MASTER'S THESIS M-2694

LAGANAS, Charles George
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A Quantitative and Qualitative Management Control Study of Selected Radar, Computer and Visual Display Equipment of a Standard Ballistic Missile Early Warning Site in the Subarctic.

A

THESIS

Submitted to the Faculty of the

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for the Degree of

MASTER OF BUSINESS ADMINISTRATION

by

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May, 1969

EVALUATION OF A COMPUTERIZED MAINTENANCE MANAGEMENT PROGRAM FOR

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Vice President for Research and Advanced Study

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I

INTRODUCTION

Scope of Study

This research study of Computerized Maintenance Management primarily consisted of studying an existing program at a large radar installation in the subarctic. The program, "AFM 66-1," is utilized by the Air Force and contracted to RCA's Company at the Ballistic Missile Early Warning Site (BMEWS) in the Alaskan Interior - the initial phase was implemented in June, 1966.

Methodology, procedures and results of the information program were studied and compared to other existing models. A survey included a broad sampling of maintenance actions. Standard operability criteria were used to determine the quality of the maintenance except for those areas which are classified by the Air Force.

Special equipment categories were chosen because of the readily available historical data collected over a period of years. Wherever possible, commercial rather than military equipment, i.e., IBM 7090 Computers, are included because it is possible to compare their performance with other installations.

Most equipment category experiences were based on empirical proofs using mathematical models. The general problem of inference making in the analysis of data output from computers will be covered in two parts :

(1) The issue of generalizing from an analysis of sample data to a population (which is usually ill defined) and to a universe (which is unknown).

(2) The problem of data error. This problem is one that appears to be of greater significance than is generally recognized.[1]

AFM 66-1 Information Flow

Basically the maintenance management program at BMEWS depends upon a maintenance data collection system whereby maintenance personnel fully document all maintenance action.[2] This information is recorded on forms which are designed to reveal the most information in the least amount of space. For the most part coded numbers are inserted into lettered blocks by the technicians - this information is later key punched onto Hollerith cards. Production analysts can quickly scan the ensuing computer printouts for possible problem areas. This procedure is described in detail and charts, graphs, tables, flow charts, etc., of the reporting system are shown.

The maintenance data collection system itself is, in the authors opinion, the foundation upon which the AFM 66-1 or any other maintenance management program is built. This section of the thesis is of primary importance and much time and space was devoted to it. Sample forms and examples are shown and explained.

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[1] A.S. Golden and T.B. Slattery, "Data Errors in Computer Use," Maintainability, (New York and London: John Wiley and Sons, Inc., 1964,) pp. 203-213.

[2] U.S. Air Force Manual, No. 66-1E, Department of the Air Force, September 1967 (Unclassified).

Although much of the language and analysis of the thesis utilizes basic statistical tools and requires no lengthy explanations, there are many technical terms used by the military and maintenance personnel that required further explanations. An appendix containing a glossary of terms defining maintenance-military-statistical terms has been provided for this purpose.

Alaskan Considerations

As with most computer applications dealing with management control the input data is highly dependent upon the human factor element involved. Methodology for reliable failure reporting from maintenance personnel takes on significant importance in a subarctic region.[3]

Personnel problems studied included attitudes, transportation difficulties in commuting, living conditions, seasonal absence and tardiness behavior, etc. Data, references and interviews were utilized wherever possible, but in the nebulous areas some of the author's opinions were expressed.

Preventive Maintenance

A comprehensive study, including regression analysis and trend analysis, was made of the AFM 66-1 Preventive Maintenance (PM) Program.

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[3]F.A. Hadden and L.W. Sepweyer, "Methodology for Reliable Failure Reporting from Maintenance Personnel," Institute of Radio Engineers (V. EM-3, Jan., 1956) pp. 27-29.

The concept of "Time Change" or planned replacement was briefly introduced. The extent to which PM (which includes planned replacement) is used, is generally regarded as a prime determinant of the failure rate of most electro-mechanical equipment.

II

MAINTENANCE DATA COLLECTION

Purposes

The foundation of any maintenance management system, whether it be a complex computerized system or a simplified manual one, is the timeliness and accuracy of the input information. This chapter will deal mostly with a Maintenance Data Collection (MDC) system, in general use throughout the Air Force and now in operation in the Alaskan Interior. Although the primary objective of the research is to evaluate computerized maintenance management with regard to a northerly and remote region, a thorough understanding of how the data are collected is necessary. Human judgement factors, data errors prior to computer analysis are especially important before examining the general problems of inference-based decisions which will be covered in later chapters.

The MDC System is an integral part of the reporting philosophy of the AFM 66-1 Program and provides a series of computer products to assist the maintenance manager at base level.[1] This system is also designed to furnish data to Air Force Logistics Command (AFLC) for material management and logistical support requirements, i.e., inventory of spare parts, storage, etc.

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[1]U.S. Air Force Automatic Data Processing Systems and Procedures AFM 171-IV Department of the Air Force, May 1968 (Unclassified).

Maintenance Data Collection Forms are utilized to rerecord production activity for all tasks accomplished by maintenance personnel and hence represent expenditure of direct labor. Coding procedures are employed to provide the capability of processing this information through punch card accounting machines and computers to produce summary reports and analysis products.[2] Coding procedures are also necessary from the human factors view point and are required for efficiency of reporting and accuracy of data.[3]

Description of Maintenance Data Collection System

Figure 2.1 shows the flow of maintenance data in detail up to the completed data forms. Figure 2.2 describes the flow of data and the removed reparables processing required for resupply. Control blocks aptly describe the different forms used and the action performed on them. The final block on Figure 2.1 shows the Air Force Computer Center, and the completed maintenance data form flow to the computer printout should be followed closely with the flow charts in Appendix A. The following three paragraphs describe the mechanics applied within the Computer Center block to convert the data forms into suitable computer inputs.[4]

1. Master ID cards are used for all data reporting (except for off-equipment that cannot be identified with major equipment groups

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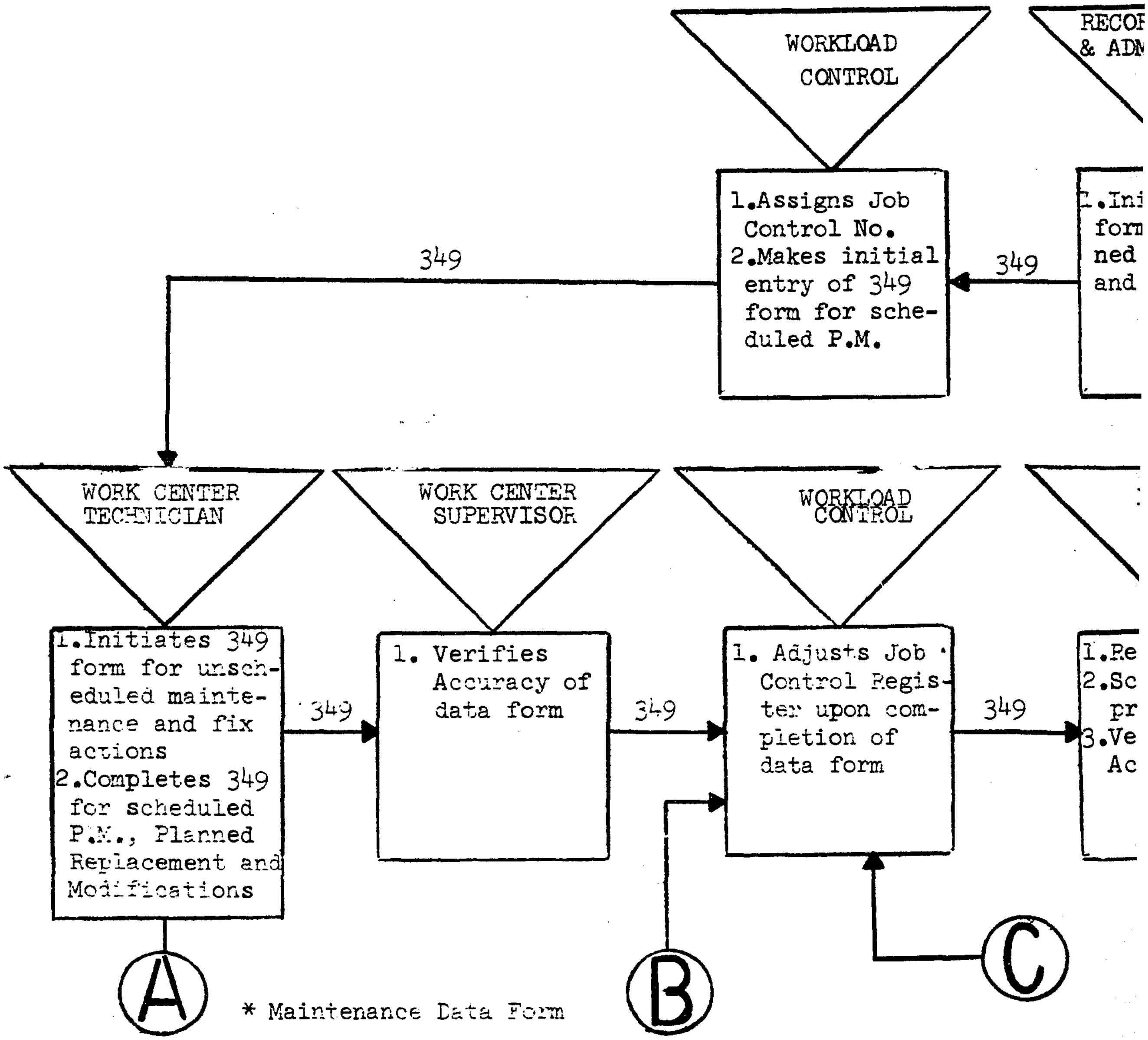
[2] U.S. Air Force Maintenance Management AFM 66-1 Department of the Air Force, June 1966 (Unclassified)

[3] Robert E. Bley, "Coding Facilitates Use of Equipment History," Factory, Vol. 122, No. 4, April 1964 pp. 110-12.

[4] AFM 171-IV, loc. cit. 41-A3-1.

FIGURE 2.1

M A I N T E N A N C E   M A N A G E M E



* Maintenance Data Form

Source: Adapted from AFM 66-1

MANAGEMENT DATA FORMS FLOW

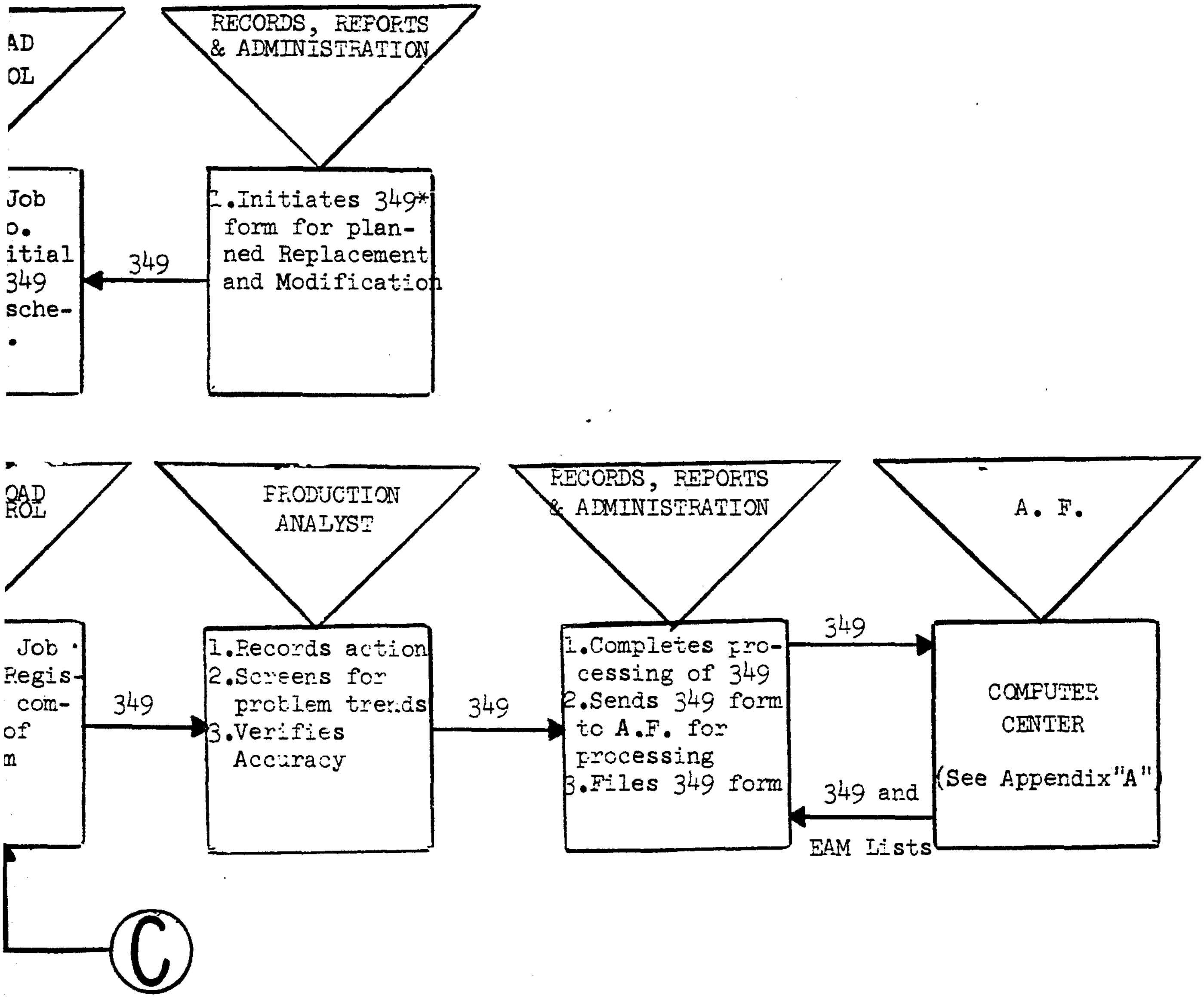
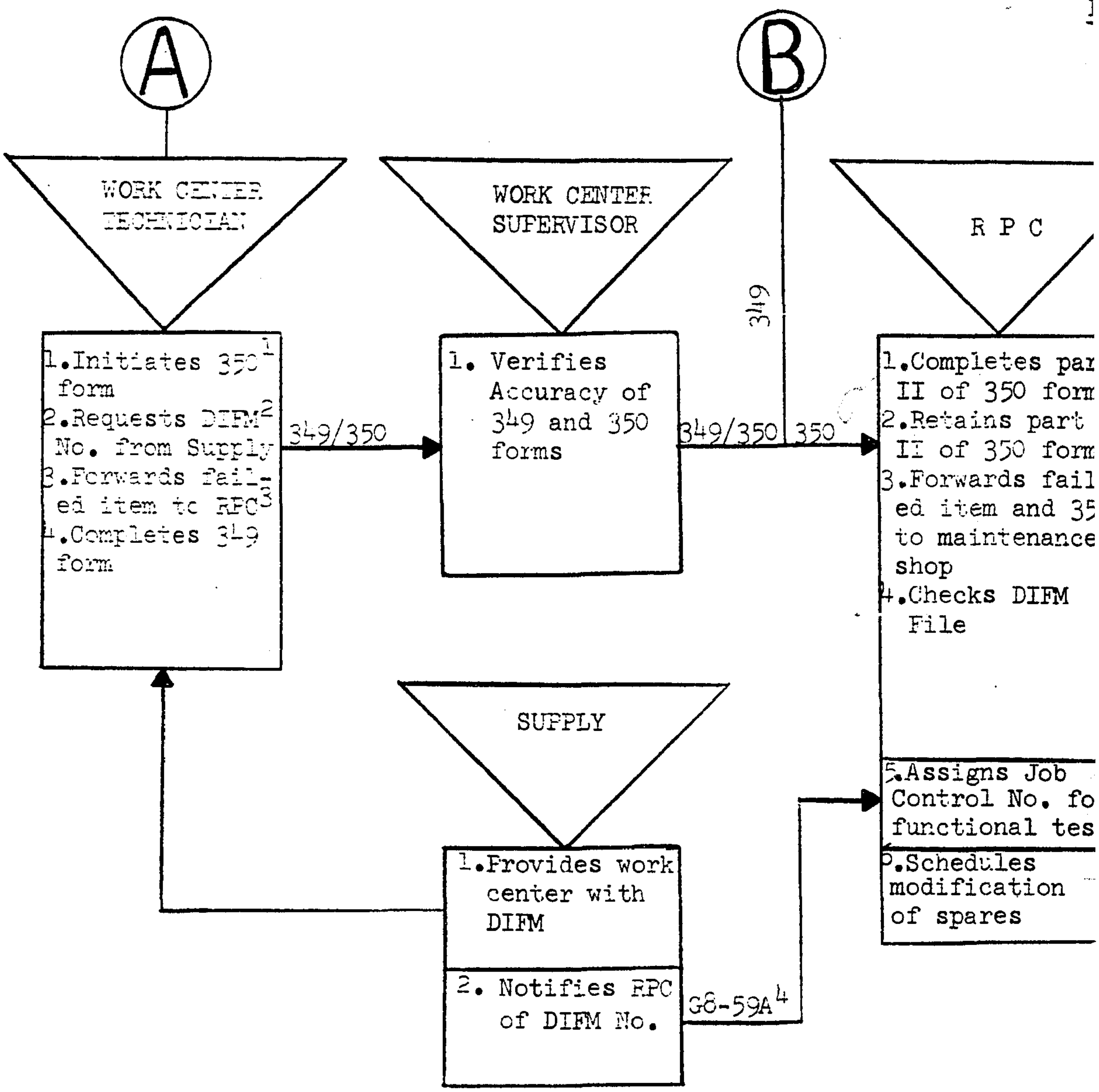


FIGURE 2.2

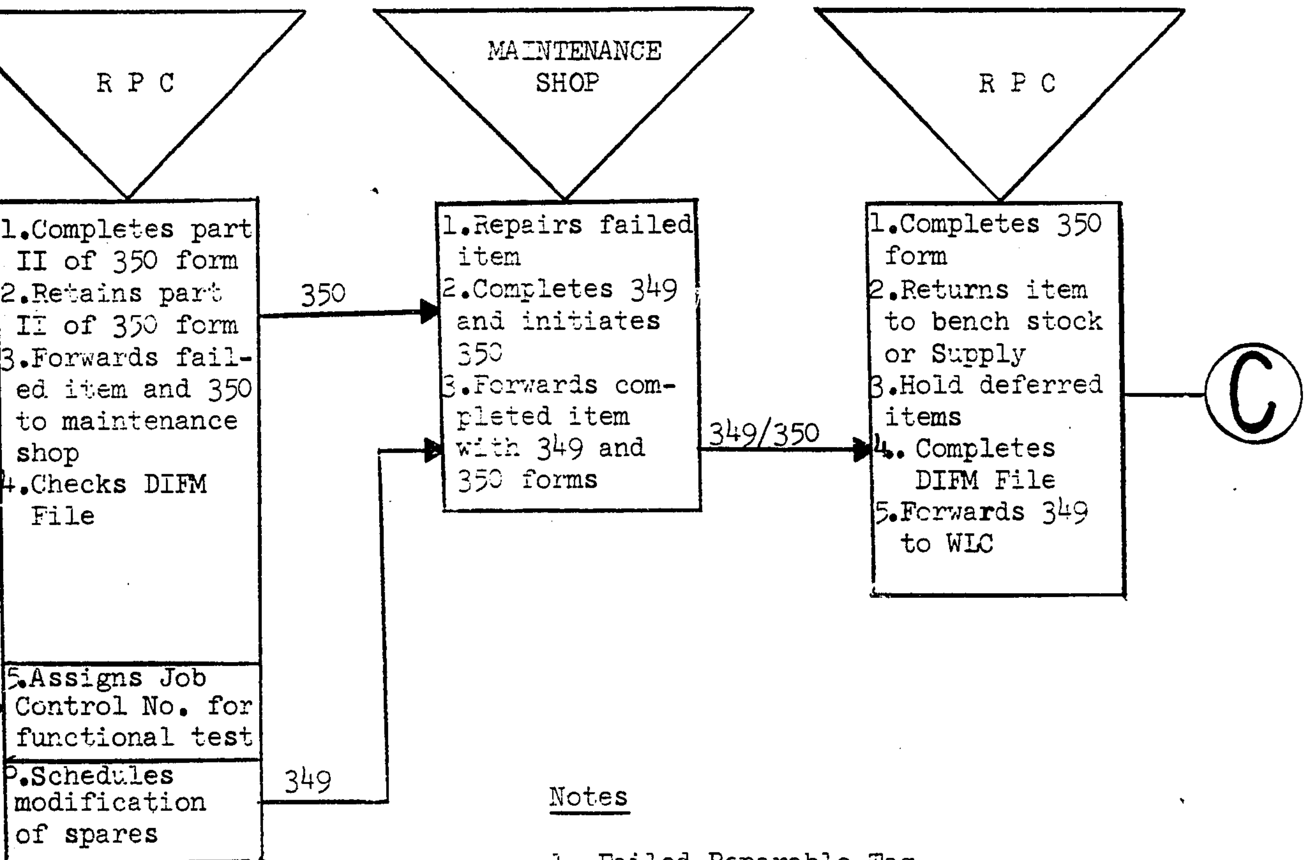
MAINTENANCE MANAGEMENT



Source: Adapted from APM 61-1

GEMENT DATA FORMS FLOW

For Removed Reparables



Notes

1. Failed Reparable Tag
2. Due In From Maintenance Form
3. Reparable Processing Center
4. Supply Accountable Document

and equipment without an ID; new or temporary equipment.) Use of these cards eliminates the need of punching the major equipment group identification serial number, major equipment group suffix and possibly the owning work center and work order prefix.

2. MDC detail cards are punched from the following Air Force Forms :

a. AF Form 349 - this is a prepunched card that is used for the scheduling of Precision Measurement Equipment (PME) and other related test equipment.

b. AF Form 349 - this form is used to record all maintenance data collection requirements that are not covered by the AF Forms 346, 210E and 212.

c. AF Form 210E - this form is used for support general work, minor fix maintenance and for scheduled inspection of ground communications-electronics-meteorological equipment (CEM).

d. AF Form 212 - this form is used to record Time Compliance Technical Orders (TCTO) actions against PME equipment that is used with AF Form 346.

3. MDC detail cards are punched from the forms mentioned in paragraph (2) above. The cards punched from the AF Form 349's are converted to the standard LOG-K97 format and are combined with the cards punched from the other AF Forms. An audit count is taken for control purposes. Edits are performed and cards found to be in error are listed for correction by the maintenance activity. After edit and correction processing, cards are reproduced and selected cards forwarded to AFLC. Cards reflecting an Assisting Work Center are reproduced, switching the Assisting Work Center with the Basic Work Center. The MDC detail cards are used to produce daily and

monthly reports. A summarization of all activity by type of equipment and organization is forwarded to higher headquarters. The Precision Measurement Equipment Master File is updated at the end of the month and used to produce monthly schedules of items due calibration and semi-annual inventories. A master preventive maintenance inspection (PMI) deck is maintained and processed monthly to provide a PMI schedule and the pre-punched AFTO form 210E.

The flow of data described in paragraph 3 above can also be followed in Figure A-1, Appendix A, page 74 Following the first operation block "start" at the top of the diagram is depicted a representation of IBM key-punched cards. These cards are sorted in an IBM EAM Sorter and proceeding along the right hand side of the chart we find that the AF Form 349's are fed into the computer (block B263, Program No. 44100). The coded data in all fields of a punched card are now compared with possible combinations from a master file for accuracy and completeness. The three outputs from block B263 Program No. 44100 are Card Punch (PCH), Card Reader (RCR) and Printer (PRT). A card that passes all the comparison tests (one comparison test is a check of the compatibility between the card End Item suffix and Work Unit Code with thousands of correct Work Unit Codes on the master file) is converted into a standard Air Force Logistics format and punched into the primary stacker for further processing. The incorrect cards punched are dropped into the auxiliary stacker and subsequently destroyed. The original cards are removed from the Card Reader after processing and are retained for "History Files." An MDC error listing, printed out on the "High Speed Printer," is forwarded to base level Systems Maintenance Analysis for corrections and subsequently returned to the Computer Center for inclusion into the monthly summaries.

Explanation of a Monthly Processing Flow Chart

Figure A-8 of Appendix A describes the flow of information from the corrected "MDC Details" keypunch cards to the Report No. 5, Part 1, Sections I and II printouts. The flag "B", encircled at the top of the flow chart, is a continuation of the corrected "On Equipment" and "Off Equipment" cards from Figure A-7. A sorting machine sorts these cards by category (identified by column punch) for inclusion into the related computer programs. In this case we are interested in block B 263 of Figure A-8, program No. 44115. The computer output of this program is a printout of a PCN Report No. 5 which is forwarded to Systems Maintenance Analysis. An example of this printout is included in Appendix B. Report No. 5, Part 1, Section I titled: "System and Component Discrepancy Summary," is basically a breakdown of the corrective maintenance (Fix Action) by End Item and Sub-system. This report is used extensively as source data to the statistical analysis in Chapter IV and is described more fully in the next chapter.

Decision Rules

All of the different computer programs in Figure A-14 of

Appendix A are identified by a five digit number beginning with 441--. The majority of the decision rules applied for these programs are made by comparing the computer results with required criteria established by the maintenance managers of the activities concerned. Descriptions of representative programs and some of the decisions involved are listed in Appendix A. The criteria for control decisions used by management are based on historical data which are updated semi-annually. The methods used in establishing control limits for some of the required criteria are described in the next chapter.

III

METHOD OF RESEARCH

Approach of the Study

The preceding background chapter described and analyzed the system used for the collection of maintenance data. This chapter presents a critique of the flow of information, including design of the reporting system. This overall reporting system is subdivided into specific functional categories listed below[1]:

B. Corrective Maintenance

1. Equipment Groups

   a. Radar Set (Detection)
   b. Radar Set (Tracker)
   c. Receiving Set
   d. Missile Impact Predictor Set, IBM 7090 Computers (MIP)
   e. Synchronizer Group
   f. Radar Control Center (CSE)
   g. Systems Checkout Set (SCO)
   h. Central Automatic Monitoring Equipment Group (CAMEG)
   i. Tactical Status Displays Set (Tac Displays)
   j. Power Plant Electrical
   k. Interconnecting Group
   l. Communications System
   m. Miscellaneous Groups

2. Off-equipment Groups

   a. Specialized Maintenance Shops
   b. Precision Measurement Equipment Laboratory

---

[1]Sections of special interest to this report are blocked for emphasis.

3. Manhour Accounting

    a. Radar Systems
    b. Data Systems
    c. Specialized Maintenance Shops
    d. Precision Measurement Equipment Laboratory

B. Preventive Maintenance

1. Equipment Groups (as listed above)

2. Manhour Accounting (by Work Center - as listed above)

C. Modification Proposals

1. Equipment Groups (as listed above)

    a. Functional Priorities
    b. Cost Priorities

2. Maintenance Management Program

    a. Data Collection
    b. Maintenance Analysis
    c. Reporting Techniques

D. Planned Replacement

1. Time Change Frequencies

2. Cost Considerations

Although the overall reporting system encompasses all of the above listed categories, this study will exclude the "Modification Proposals of Equipment Groups" (C.1.) and those subsystems concerned with manhour accounting and cost considerations. The "SMS/PME Off-Equipment Groups" (A.2.) which is mainly concerned with reparable spares has also been excluded.

Basic Reports

Figure 2.1 of Chapter 2 depicted an Air Force Computer Center as the final block in the maintenance management data forms flow. The flow charts in Appendix A result in computer printouts called Product Control Number (PCN) reports. The reports have coded numbers (not listed) and the titles are as follows :

1. PCN Report No. 1 - Daily Production
2. PCN Report No. 2 - Monthly Production Summary
3. PCN Report No. 3 - Monthly Labor Hours Summary
4. PCN Report No. 4 - Monthly Work Order Summary
5. PCN Report No. 5 - System and Component Discrepancy Summary
6. PCN Report No. 6 - End Item Malfunction Summary
7. PCN Report No. 7 - Action Taken Codes Summary
8. PCN Report No. 8 - Failed Part Summary
9. PCN Report No. 9 - Precision Measurement (PME) Schedule

The basic format of each report is a computerized printout representing the breakdown of the maintenance data into various categories, i.e., Work Center, Work Unit Code, End Item, Supply Stock Number, etc. Sub-minor, minor, intermediate and major totals are all broken down within these categories. For example, page 98 of Appendix B is a copy of a typical "Monthly Work Order Summary" Report No. 4, Part 1, Section 1. Line entry No. 5 represents the PMEL Equipment Group identified by prefix and suffix under the "WO" heading; a minor total of 5 units produced under the "UP" heading; a minor total of 7.9 labor hours expended for Work Center No. 52103 under the "Hours" and "WC" headings respectively[2].

Flow of Information

Monthly computerized PCN printouts are forwarded to the Air Force (including the A.F. Logistics Command,) base level managers, and to Systems Maintenance Analysis (SMA). At SMA the production analyst verifies the accuracy of the reports; reviews data for significant trends in equipment groups, material deficiences and manhour consumption; identifies end items exceeding control limits and forwards this information to the Maintenance Analysis.

Control Concept and Applications

The prescribed analytical methodology utilized by the maintenance analysis is through the general use of descriptive statistics. Special emphasis is placed on the extensive use of control charts. Mean averages for maintenance failures (defined as fix actions) are calculated for each end item; standard deviations are also calculated and the control limit is specified as the mean average plus one standard deviation. Control limits are recalculated every six months.

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[2]It is not within the scope of this thesis to give a detailed illustration and explanation of each printout format, however, an example of each of them has been provided in Appendix B for those who wish to study the reports further.

The intuitive reasoning of the above philosophy is that the monthly maintenance fix actions for the individual end items will approximate the "Normal Curve." When an end item control limit is exceeded, the analyst must analyze, evaluate and report his conclusions on the associated maintenance action for that particular monthly period. This method is carried over into all functional test, bench check, condemned, deferred and NRTS actions[3]. Control limits are also established on high value items and consumption of manhours.

The control chart method is further refined within an end item by the use of the Work Unit Code (WUC). This is an important concept to the AFM 66-1 program and the following example will help describe it.

Example: WUC of C A J D C

All WUC's have five digits. The computer program has determined through the identification of the Work Order Number (WO) of the data form that this WUC is broken down as follows :

C - Central Processing Unit No. 1 (CPU),

A - CPU Cabinet No. 1,

J - Gate "A",

D - Chassis No. 4,

C - IBM module (DEZA) 371321.

This WUC identifies the failed item to a specific module within

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[3]A glossary has been provided for the reader who is not familiar with these and other maintenance/military terms.

the end item. Thus the analyst can in some cases, isolate a specific module, location, chassis, gate and cabinet which fails more often than like items.

The overall Air Force maintenance control system, based on generally established statistical control routines, is a requirement for most Air Force bases. In the professional concensus, predicated upon numerous interviews with contractor and military personnel, it has worked exceptionally well for the Strategic Air Command where thousands of homogeneous engines have lent themselves readily to descriptive and analytical statistics. However, in this thesis research there is preliminary evidence suggesting that :

a. Details of management control for activities actually implemented in the maintenance are "inefficient", i.e., maintenance conflict with mission directives and heterogeneous subsystem equipment groups.

b. The Alaskan Interior regional experience does not conform to inherently anticipated minor problems of the information systems.

Therefore, the next chapter will be devoted to the major aspects of the AFM 66-1 Maintenance Management Program covering all corrective maintenance actions in special equipment subsystems for the past two years. All thirteen equipment subsystems (End Items) will be combined and analyzed by comparing the observed monthly CM fix action frequency with a calculated hypothetical normal frequency distribution.

IV

STATISTICAL ANALYSIS AND SYNTHESIS OF THE MAINTENANCE MANAGEMENT RESULTS

Introduction

The statistical evidence presented by AFM 66-1 on Maintenance Management for the Alaskan Interior was based on the following provisions :

(1) The sampled input was random and hence represents.

(2) The population (μ) is "normally" distributed.

(3) The sample standard deviation (s) is a valid substitution for the population standard deviation (σ).

(4) An initial presumption is made that the mean ($\overline{x}$, where n = 24) is equal to the population mean ($\overline{X}_{\mu}$).

General Description of Tables

This chapter contains twenty-one tables presented in the following sequence :

(1) Tables 4.1 - 4.3 Combined thirteen subsystems (End Items).

a. cumulative frequency of monthly CM fix actions.

b. computation of population parameters.

c. fitting a hypothetical "normal" curve to the observed CM fix action histogram

(2) Tables 4.4 - 4.6 MIP End Item (a, b, c above)

(3) Tables 4.7 - 4.9 SCO End Item (a, b, c above)

(4) Tables 4.10 - 4.12 Detection Radar End Item (a, b, c above)

(5) Tables 4.13 - 4.15 CAMEG End Item (a, b, c above)

(6) Tables 4.16 - 4.18 Tactical Displays End Item (a, b, c above)

(7) Tables 4.19 - 4.21 Master Synchronizer End Item (a, b, c above)

The six subsystems selected represented 12,157 of the combined 17,400 CM fix actions for a two year period ending December 31, 1968. The other seven items were either classified or did not have complete two year data history of CM Fix Actions. Also included with the graphs are figures and charts representing the observed monthly frequency histograms and the hypothetical "normal" curve for each category.

Table 4.1

MONTHLY CORRECTIVE MAINTENANCE (CM) FIX ACTIONS FOR TOTAL END ITEMS IN A NORTHERN BALLISTIC MISSILE EARLY WARNING SITE, 1967-1968.

CM fix actions per month	mid-point	Frequency	Cumulative frequency percent
200- 299	250	0	
300- 399	350	1	4.1
400- 499	450	3	16.7
500- 599	550	2	25.0
600- 699	650	4	41.7
700- 799	750	4	58.3
800- 899	850	6	83.3
900- 999	950	3	95.8
1,000-1,099	1,050	1	100.0

Source: U.S.A.F. Monthly Product Control Number printouts (PCN 44144A Report No. 4, Part 1, Group 1) 1967-1968 ... R.C.A. Service Co. Management Evaluation Charts - same period.

Table 4.2

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR TOTAL END ITEMS 1967 - 1968 MONTHLY CM FIX ACTIONS

i = 100 CM Fix Actions	m	f	fm	$\lvert m-\bar{x} \rvert$	$f\lvert m-\bar{x} \rvert$	$f(m-\bar{x})^2$
2.0- 2.99	2.5	0	0	4.75	0	0
3.0- 3.99	3.5	1	3.5	3.75	3.75	14.0625
4.0- 4.99	4.5	3	13.5	2.75	7.25	19.9375
5.0- 5.99	5.5	2	11.0	1.75	3.50	6.1250
6.0- 6.99	6.5	4	26.0	0.75	3.00	2.2500
7.0- 7.99	7.5	4	30.0	0.25	1.00	0.2500
8.0- 8.99	8.5	6	51.0	1.25	7.50	9.3750
9.0- 9.99	9.5	3	28.5	2.25	6.75	15.1875
10.0-10.99	10.5	1	10.5	3.25	3.25	10.5625
Sum	n/a	24	174.0	20.75	36.00	77.7500

Mean = $\bar{x}$ = 725

Average Deviation = A.D. = 150

Sample Standard Deviation = s = $\pm$ 180

Median = 750

Coefficient of Skewness = -.417 (negatively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$ = .248

Source: Calculated from Table 4.1.

Table 4.3

FITTING A NORMAL CURVE TO TOTAL END ITEM CM FIX ACTION HISTOGRAM[1]

classes	mid-point	Frequency (x) observed (for (m)	$z = \frac{m-\bar{x}}{s}$	area	Hypothetical (f) normally distributed on m.*
200- 299	250	0	-2.64	.4959	0.164
300- 399	350	1	-2.08	.4812	0.612
400- 499	450	3	-1.53	.4370	1.650
500- 599	550	2	-0.97	.3340	3.290
600- 699	650	4	-0.42	.1628	4.865
700- 799	750	4	0.14	.0557	5.279
800- 899	850	6	0.69	.2549	4.279
900- 999	950	3	1.25	.3944	2.439
1,000-1,099	1,050	1	1.81	.4649	1,040
1,100-1,199	1,150	0	2.36	.4909	0.346

x = Monthly CM Fix Actions

Mean = $\bar{x}$ = 725 = Hypothetical frequency of 5.318

n = 24, s = + 180, i = 100, N = 17,400

$$* \text{ Col. } 6 = y = \frac{ni}{s} \; \frac{1}{2} \; e^{-} \; \left(\frac{m-\bar{x}}{s}\right)^{2}$$

= 13333 x value from Table 3 of referenced text.

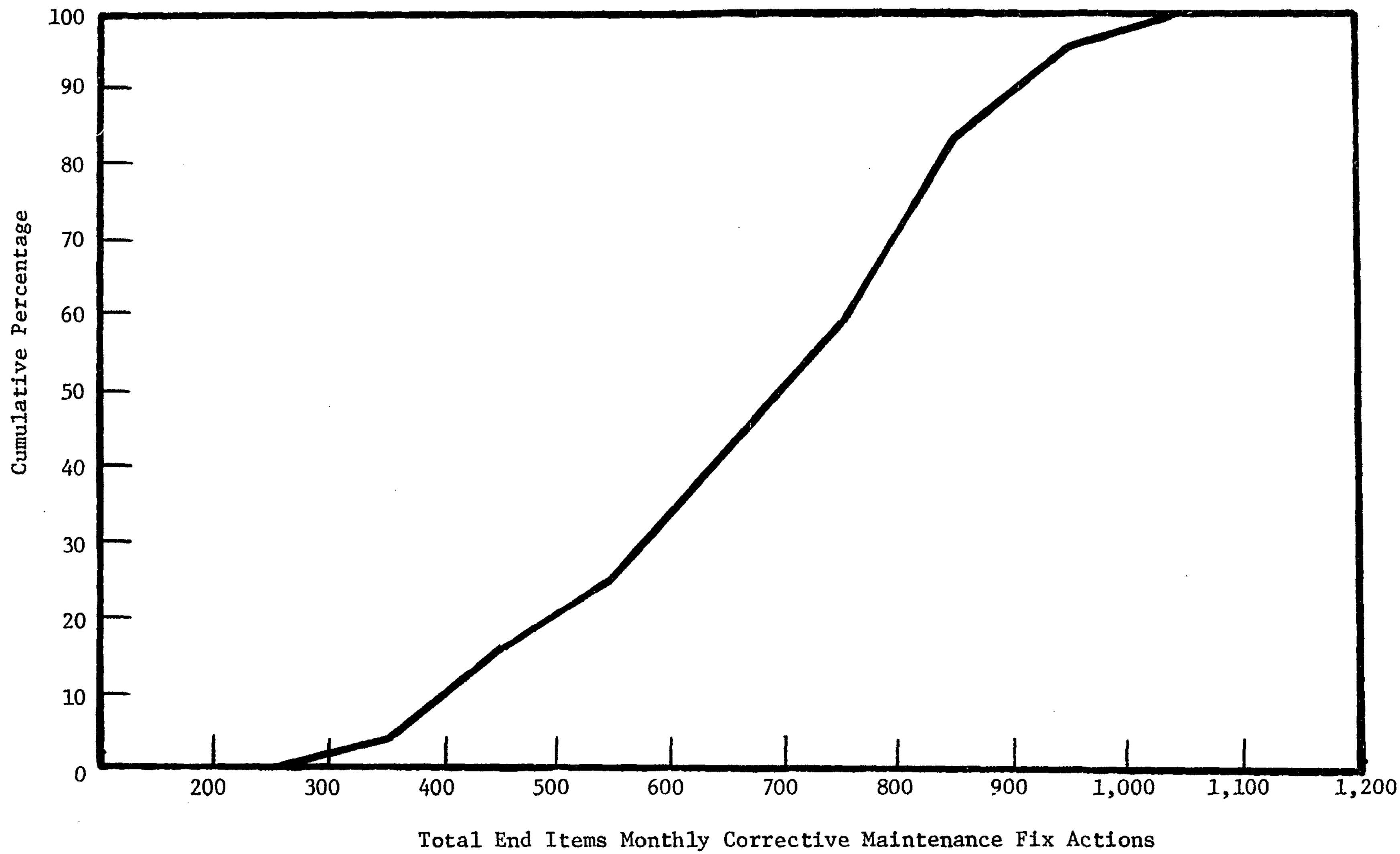
The above method has been utilized on fitting the normal curve to the Individual Sample End Items

Source: Calculated from PCN Reports No. 5, Part 1, Section 1. PCN 44115A, "System and Component Discrepancy Summary", 1967-68.

[1] Wilfred J. Dixon and Frank J. Massey, Introduction to Statistical Analysis, (New York: McGraw-Hill Book Company, Inc., 1951), pp. 47-64.

Figure 4.1

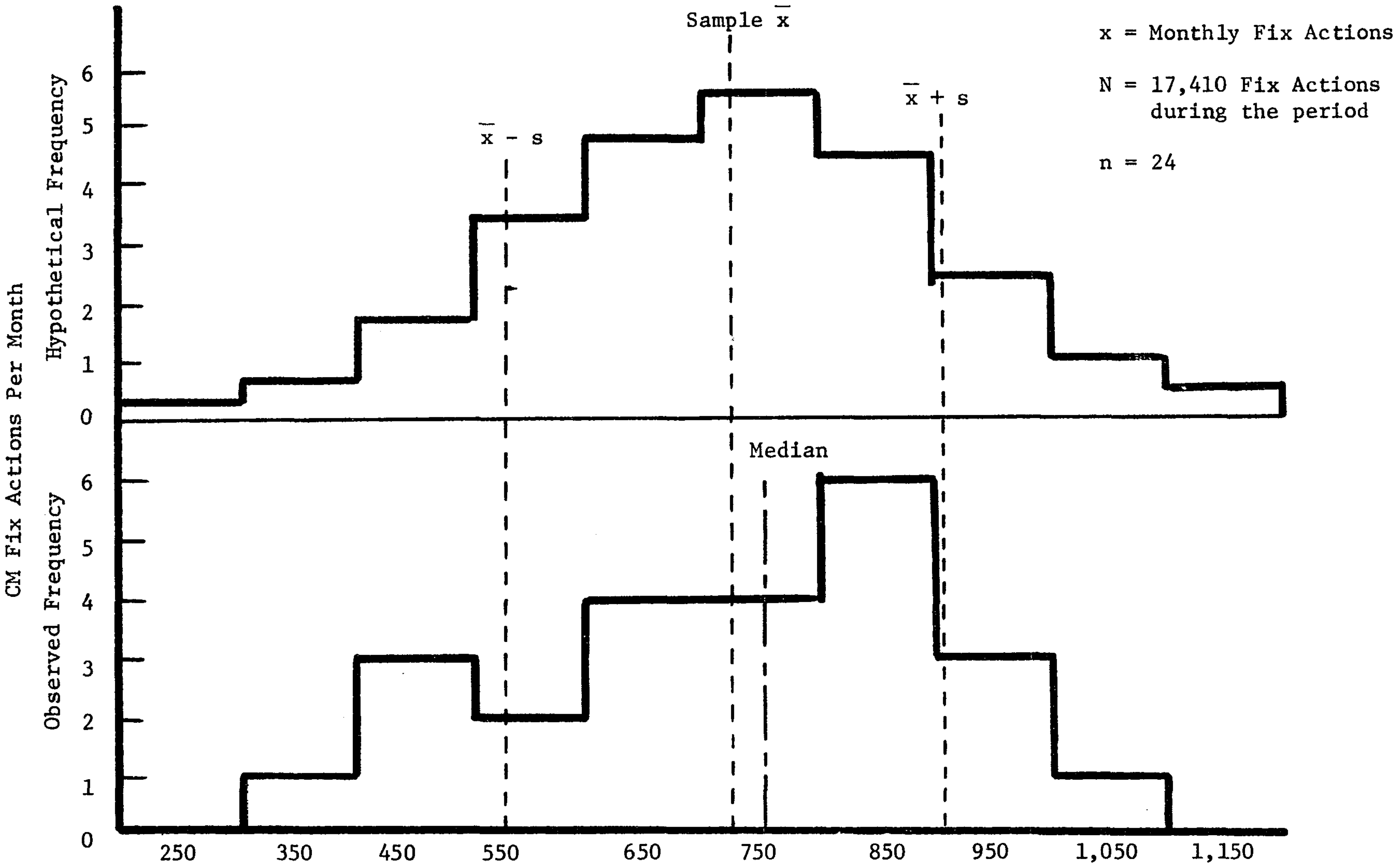
CUMULATIVE - PERCENT CURVE: PERCENT OF MONTHS CONTAINING CM FIX ACTIONS FOR COMBINED SUBSYSTEMS



Source: Table 4.1

Figure 4.2

OBSERVED FREQUENCY HISTOGRAM - HYPOTHETICAL FREQUENCY HISTOGRAM:
COMBINED SUBSYSTEM GROUPS 1967-1968



Source: Tables 4.1 - 4.3

Table 4.4

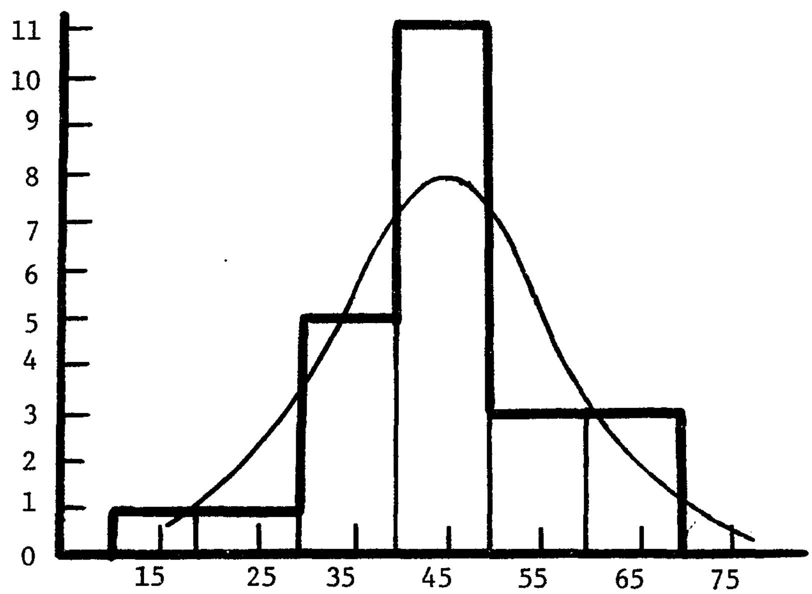
MONTHLY CORRECTIVE MAINTENANCE (CM) FIX ACTIONS FOR MIP* 1967-1968

CM Fix Actions per month	mid-point	Frequency	Cumulative Frequency (percent)
10-19.99	15	1	4.1
20-29.99	25	1	8.3
30-39.99	35	5	29.1
40-49.99	45	11	75.0
50-59.99	55	3	87.0
60-69.99	65	3	100.0

* Missile Impact Predictor - Composed of two IBM 7090 general purpose scientific digital computers, Binary Clocks, Real Time Channels and EAM Equipment

Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, "System and Component Discrepancy Summary", 1967-1968.

Figure 4.3
MIP OBSERVED HISTOGRAM - HYPOTHETICAL "NORMAL" CURVE



Source: Tables 4.4 and 4.6

Table 4.5

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR MIP
1967-1968 MONTHLY CM FIX ACTIONS

CM Fix Actions	m	f	fm	$\lvert m-\bar{x} \rvert$	$f\lvert m-\bar{x} \rvert$	$f(m-\bar{x})^2$
10-19.99	15	1	15	29.58	29.58	874.98
20-29.99	25	1	25	19.58	19.58	383.38
30-39.99	35	5	175	9.58	47.90	458.88
40-49.99	45	11	495	0.42	4.62	1.94
50-59.99	55	3	165	10.42	31.26	325.73
60-69.99	65	3	195	20.42	61.26	1250.93
Sum	n/a	24	1070	90.00	194.20	3295.84

Mean = $\bar{x}$ = 44.58

Average Deviation = A.D. = 8.09

Sample Standard Deviation = s = $\pm$ 11.72

Median = 44.54

Coefficient of Skewness = 0.010 (positively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$ = .263

Source: Calculated from Table 4.4

Table 4.6

FITTING A NORMAL CURVE TO MIP CM FIX ACTION HISTOGRAM[1]

(x) classes	mid-point	Frequency (x) observed for (m)	$z=\frac{m-\bar{x}}{s}$	area	Hypothetical (f) normally distributed on (m)
10-19.99	15	1	-2.52	.4941	0.342
20-29.99	25	1	-1.67	.4525	2.025
30-39.99	35	5	-0.82	.2939	5.837
40-49.99	45	11	0.03	.0120	8.167
50-59.99	55	3	0.89	.3133	5.499
60-69.99	65	3	1.74	.4591	1.798
70-79.99	75	0	2.59	.4952	0.285

(x) = Monthly CM Fix Actions

Mean = $\bar{x}$ = 44.6 = Hypothetical frequency of 8.169

n = 24, s = $\pm$ 11.72, i = 10, N = 1070.

Source: Calculated from PCN Reports No. 5, Part 1, Section 1. PCN 44115A, "System & Component Discrepancy Summary," 1967-1968.

[1]See Table 4.3 notes for explanation to above table.

Table 4.7

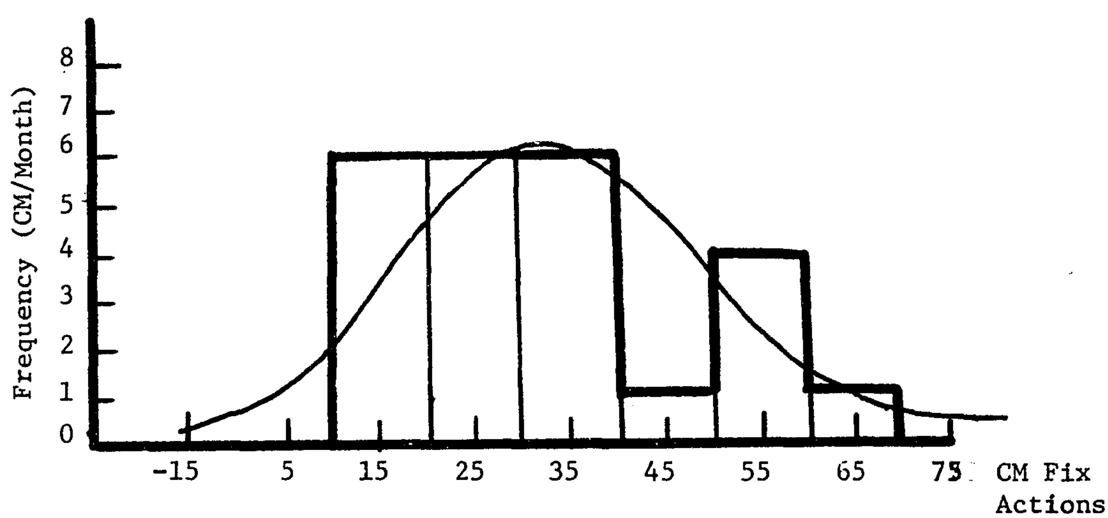
MONTHLY CM FIX ACTIONS FOR SCO* 1967-1968

CM Fix Actions per month	midpoint	Frequency	Cumulative frequency (per cent)
10-19.9	15	6	25.0
20-29.9	25	6	50.0
30-39.9	35	6	75.0
40-49.9	45	1	79.0
50-59.9	55	4	95.8
60-69.9	65	1	100.0

*System Checkout System-Special purpose RCA/Indiana General digital Computer with display chassis.

Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, "System & Component Discrepancy Summary" 1967-1968.

Figure 4.4 SCO Observed Histogram - Hypothetical "Normal" Curve



Source: Tables 4.7 and 4.9

Table 4.8

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR SCO
1967-1968 CM FIX ACTIONS

CM Fix Actions	m	f	fm	$\lvert m-\bar{x}\rvert$	$f\lvert m-\bar{x}\rvert$	$f(m-\bar{x})^2$
10.0-19.99	15	6	90	17.5	105.0	1837.0
20.0-29.99	25	6	150	7.5	45.0	337.5
30.0-39.99	35	6	210	2.5	15.0	37.5
40.0-49.99	45	1	45	12.5	12.5	156.2
50.0-59.99	55	4	220	22.5	90.0	2025.0
60.0-69.99	65	1	65	32.5	32.5	1056.2
Sum	n/a	24	780	95.0	300.0	5449.4

Mean = $\bar{x}$ = 32.5

Average Deviation = A.D. = 12.5

Sample Standard Deviation = s = $\pm$15.1

Median = Md. = 30.0

Coefficient of Skewness = 0.496 (positively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$ = 0.465

Source: Calculated from Table 4.7.

Table 4.9

FITTING A NORMAL CURVE TO SCO CM FIX ACTION HISTOGRAM[1]

(x) classes	midpoint	Frequency (x) observed for (m)	$z=\frac{m-\bar{x}}{s}$	area	Hypothetical (f) normally distributed on (m)
10-19.99	15	6	-1.16	.3770	3.235
20-29.99	25	6	-0.50	.1915	5.595
30-39.99	35	6	0.16	.0636	6.259
40-49.99	45	1	0.83	.2967	4.492
50-59.99	55	4	1.49	.4319	2.090
60-69.99	65	1	2.15	.4842	0.628
70-79.99	75	0	2.81	.4975	0.122

(x) = Monthly CM Fix Actions

Mean = $\bar{x}$ = 32.5 - Hypothetical frequency of 6.338

n = 24, s = $\pm$15.1, i = 10, N = 780

Source: Calculated from PCN Reports No. 5, Part 1, Section 1. PCN 44115A, "System & Component Discrepancy Summary," 1967-1968.

[1]See Table 4.3 notes for explanation to above table.

Table 4.10

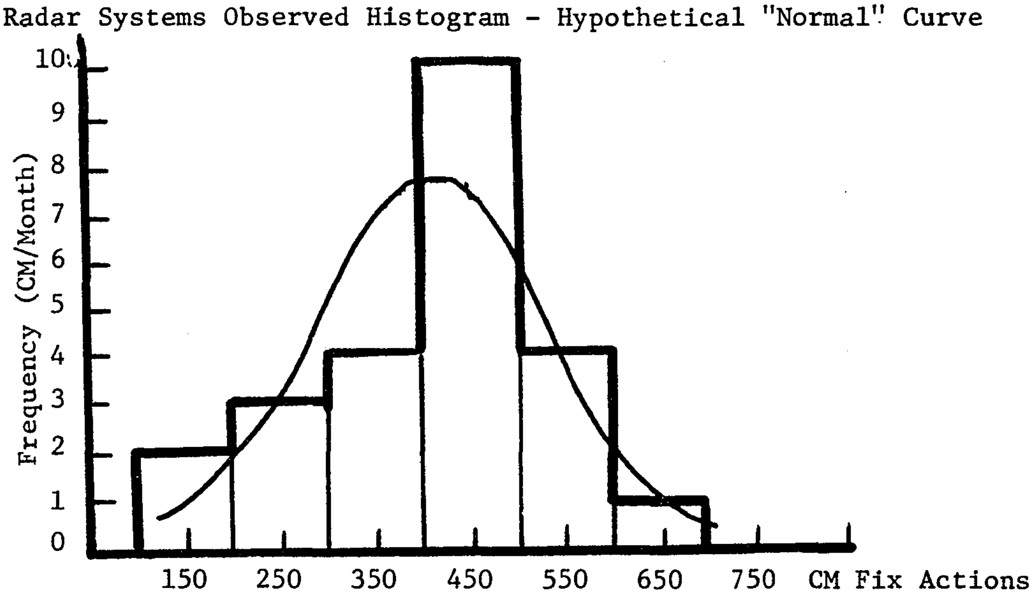
MONTHLY CM FIX ACTIONS FOR RADAR SYSTEMS* 1967-1968

CM Fix Actions per month	midpoint	Frequency	Cumulative frequency (per cent)
100-199	150	2	8.3
200-299	250	3	20.8
300-399	350	4	37.5
400-499	450	10	79.2
500-599	550	4	95.8
600-699	650	1	100.0

*Radar Systems - Aggregate includes Mechanical devices, solid state devices and vacuum tubes.

Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, Systems & Component Discrepancy Summary" 1967-1968.

Figure 4.5
Radar Systems Observed Histogram - Hypothetical "Normal" Curve



Source: Tables 4.10 and 4.12

Table 4.11

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR RADAR SYSTEMS
1967-1968 MONTHLY CM FIX ACTIONS

i = 100 CM Fix Actions	m	f	fm	$\lvert m-\bar{x}\rvert$	$f\lvert m-\bar{x}\rvert$	$f(m-\bar{x})^2$
1.00-1.99	1.5	2	3.0	2.5	5.0	12.50
2.00-2.99	2.5	3	7.5	1.5	4.5	6.75
3.00-3.99	3.5	4	14.0	0.5	2.0	1.00
4.00-4.99	4.5	10	45.0	0.5	5.0	2.50
5.00-5.99	5.5	4	22.0	1.5	6.0	9.00
6.00-6.99	6.5	1	6.5	2.5	2.5	6.25
Sum	n/a	24	98.0	9.0	25.0	38.00

Mean = $\bar{x}$ = 408

Average Deviation = A.D. = 104

Sample Standard Deviation = s = $\pm$ 126

Median = Md. = 422

Coefficient of Skewness = -.333 (negatively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$ = .309

Source: Calculated from Table 4.10.

Table 4.12

FITTING A NORMAL CURVE TO RADAR SYSTEMS CM FIX ACTION HISTOGRAM [1]

(x) classes	midpoint	Frequency (x) observed for (m)	$z=\frac{m-\bar{x}}{ss}$	area	hypothetical (f) normally distributed on (m)
100-199	150	2	-2.05	.4798	0.930
200-299	250	3	-1.25	.3944	3.478
300-399	350	4	-0.46	.1772	6.837
400-499	450	10	0.33	.1293	7.197
500-599	550	4	1.13	.3708	4.014
600-699	650	1	1.92	.4726	1.204
700-799	750	0	2.71	.4966	0.192

(x) = Monthly CM Fix Actions

Mean = $\bar{x}$ = 408 = Hypothetical frequency of 7.599

n = 24, s = $\pm$ 126, i = 100, N = 9800.

Source: Calculated from PCN Reports No. 5, Part 1, Section 1. Pcn 44115A, "System & Component Discrepancy Summary," 1967-1968.

[1] See Table 4.3 notes for explanation to above table.

Table 4.13

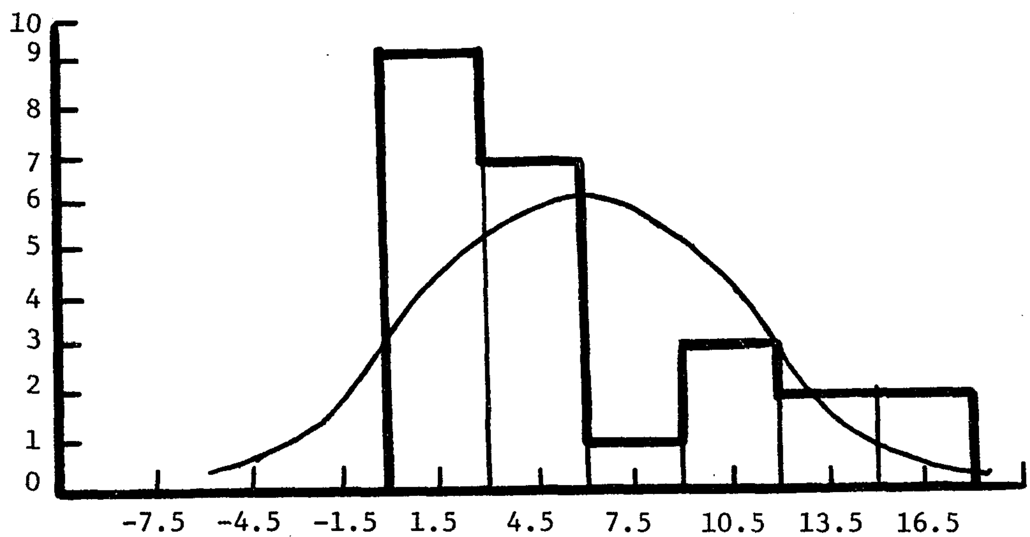
MONTHLY CM FIX ACTIONS FOR CAMEG* 1967-1968

CM Fix Actions per month	midpoint	Frequency	Cumulative Frequency (per cent)
0-2.9	1.5	9	37.5
3.0-5.9	4.5	7	66.7
6.0-8.9	7.5	1	70.8
9.0-11.9	10.5	3	83.3
12.0-14.9	13.5	2	91.7
15.0-17.9	16.5	2	100.0

*Central Automatic Monitoring Equipment Group.

Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, "System & Component Discrepancy Summary" 1967-1968.

Figure 4.6
CAMEG Observed Histogram - Hypothetical "Normal" Curve



Source: Tables 4.13 and 4.15

Table 4.14

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR CAMEG 1967-1968 MONTHLY CM FIX ACTIONS

CM Fix Actions	m	f	fm	$\lvert m-\bar{x}\rvert$	$f\lvert m-\bar{x}\rvert$	$f(m-\bar{x})^2$
0- 2.99	1.5	9	13.5	4.5	40.5	182.25
3.0- 5.99	4.5	7	31.5	1.5	10.5	15.75
6.0- 8.99	7.5	1	7.5	1.5	1.5	2.25
9.0-11.99	10.5	3	31.5	4.5	13.5	60.75
12.0-14.99	13.5	2	27.0	7.5	15.0	112.50
15.0-17.99	16.5	2	33.0	10.5	21.0	220.50
Sum	n/a	24	144.0	30.0	102.0	594.00

Mean = $\bar{x}$ = 6.0

Average Deviation = A.D. = 4.25

Sample Standard Deviation = s = ± 4.97

Median = Md. = 4.28

Coefficient of Skewness = 1.04 (positively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$ = .828

Source: Calculated from Table 4.13.

Table 4.15

FITTING A NORMAL CURVE TO CAMEG CM FIX ACTION HISTOGRAM[1]

(x) classes	midpoint	Frequency (x) observed for (m)	$z=\frac{m-\bar{x}}{s}$	area	Hypothetical (f) normally distributed on (m)
0.0- 2.99	1.5	1	-0.91	.3186	3.821
3.0- 5.99	4.5	1	-0.30	.1179	5.526
6.0- 8.99	7.5	5	0.30	.1179	5.526
9.0-11.99	10.5	11	0.91	.3186	3.821
12.0-14.99	13.5	3	1.51	.4345	1.849
15.0-17.99	16.5	3	2.11	.4826	0.624
18.0-20.99	19.5	0	2.72	.4967	0.143

(x) = Monthly CM Fix Actions

Mean = $\bar{x}$ = 6.0 = Hypothetical frequency of 5.780

n = 24, s = $\pm$4.97, i = 3, N = 144

Source: Calculated from PCN Reports No. 5, Part 1, Section 1. PCN 44115A, "System & Component Discrepancy Summary," 1967-1968

[1] See Table 4.3 notes for explanation to above table.

Table 4.16

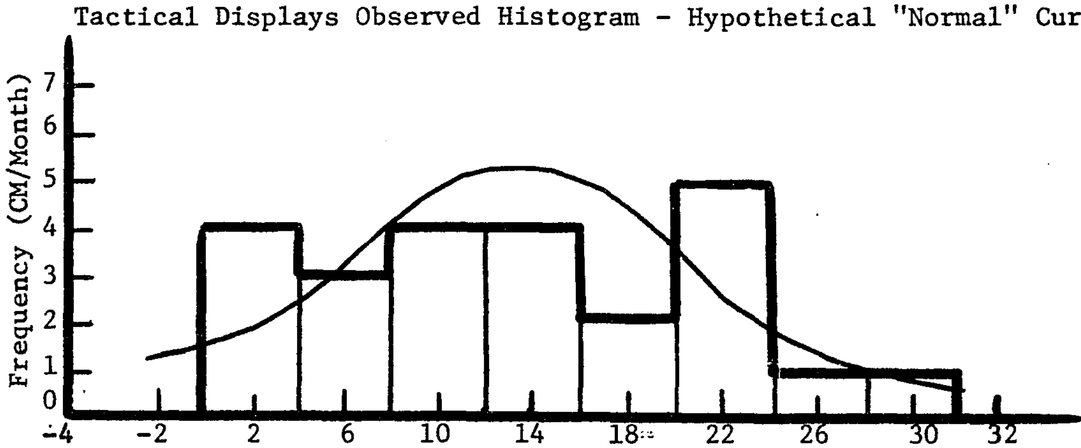
MONTHLY CORRECTIVE MAINTENANCE FIX ACTIONS FOR TACTICAL DISPLAYS* 1967-1968

CM Fix Actions per month	midpoint	Frequency	Cumulative Frequency (per cent)
0.0- 3.99	2	4	16.7
4.0- 7.99	6	3	29.2
8.0-11.99	10	4	45.8
12.0-15.99	14	4	62.5
16.0-19.99	18	2	70.8
20.0-23.99	22	5	91.7
24.0-27.99	26	1	95.8
28.0-31.99	30	1	100.00

*Visual Display Circuitry plus Analex Printers.

Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, "System & Component Discrepancy Summary" 1967-1968.

Figure 4.7
Tactical Displays Observed Histogram - Hypothetical "Normal" Curve



Source: Tables 4.16 and 4.18

Table 4.17

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR TACTICAL DISPLAYS 1967-1968 MONTHLY CM FIX ACTIONS

CM Fix Actions	m	f	fm	$\lvert m-\bar{x}\rvert$	$f\lvert m-\bar{x}\rvert$	$f(m-\bar{x})^2$
0- 3.99	2	4	8	11.50	46.00	529.00
4.0- 7.99	6	3	18	7.50	22.50	168.75
8.0-11.99	10	4	40	3.50	14.00	49.00
12.0-15.99	14	4	56	.50	2.00	1.00
16.0-19.99	18	2	36	4.50	9.00	40.50
20.0-23.99	22	5	110	8.50	42.50	361.25
24.0-27.99	26	1	26	12.50	12.50	156.25
28.0-31.99	30	1	30	16.50	16.50	272.25
Sum	n/a	24	324	65.00	165.00	1578.00

Mean = $\bar{x}$ = 13.50

Average Deviation = A.D. = 6.88

Sample Standard Deviation = s = ± 8.11

Median = Md. = 13.0

Coefficient of Skewness = 0.185 (positively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$ = .601

Source: Calculated from Table 4.16.

Table 4.18

FITTING A NORMAL CURVE TO TACTICAL DIXPLAYS CM FIX ACTION HISTOGRAM[1]

(x) classes	midpoint	Frequency (x) observed for (m)	$z = \frac{m-\bar{x}}{s}$	area	Hypothetical (f) normally distributed on (m).
0.0- 3.99	2	4	-1.42	.4222	1.722
4.0- 7.99	6	3	-0.92	.3212	3.091
8.0-11.99	10	4	-0.43	.1664	4.302
12.0-15.99	14	4	0.06	.0239	4.711
16.0-19.99	18	2	0.56	.2123	4.034
20.0-23.99	22	5	1.05	.3531	2.720
24.0-27.99	26	1	1.54	.4382	1.442
28.0-31.99	30	1	2.03	.4788	0.601

(x) = Monthly CM Fix Actions

Mean = $\bar{x}$ - 13.50 - Hypothetical frequency of 4.719

n = 24, s = $\pm$8.11, i = 4, N = 324

Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, "System & Component Discrepancy Summary," 1967-1968.

[1] See Table 4.3 notes for explanation to above table.

Table 4.19

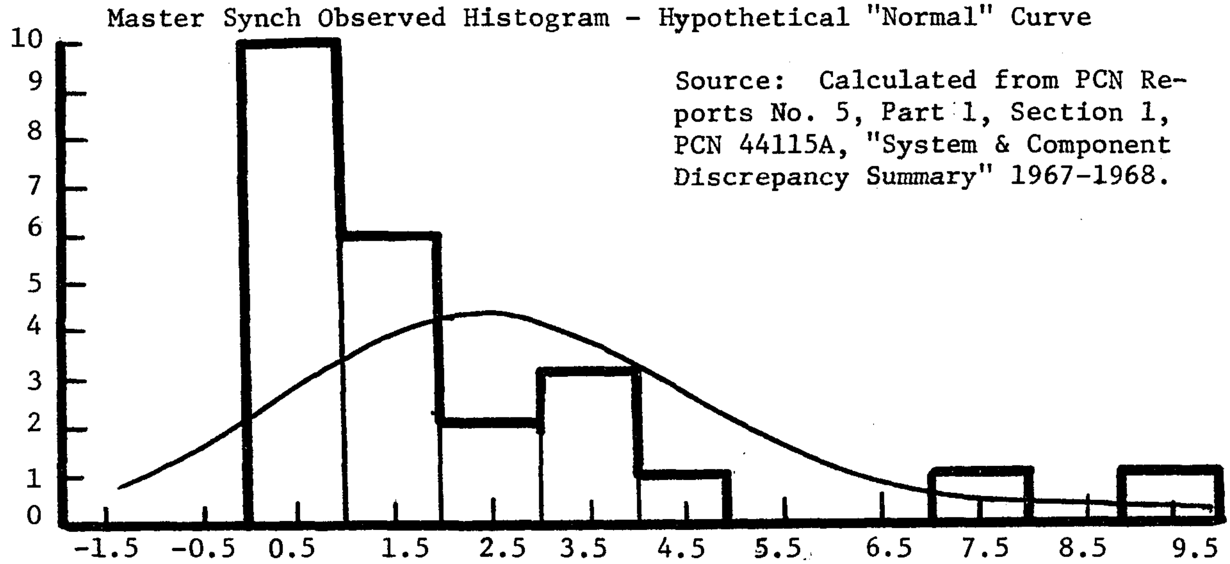
MONTHLY CM FIX ACTIONS FOR MASTER SYNCHRONIZER* 1967-1968

CM Fix Actions per month	midpoint	Frequency	Cumulative Frequency (per cent)
0-0.9	0.5	10	41.7
1.0-1.9	1.5	6	66.7
2.0-2.9	2.5	2	75.0
3.0-3.9	3.5	3	87.5
4.0-4.9	4.5	1	91.7
5.0-5.9	5.5	0	91.7
6.0-6.9	6.5	0	91.7
7.0-7.9	7.5	1	95.8
8.0-8.9	8.5	0	95.8
9.0-9.9	9.5	1	100.0

*Synchronizer Group - Solid State Switching and Synchronous Circuitry.

Figure 4.8

Master Synch Observed Histogram - Hypothetical "Normal" Curve



Source: Calculated from PCN Reports No. 5, Part 1, Section 1, PCN 44115A, "System & Component Discrepancy Summary" 1967-1968.

Source: Tables 4.19 and 4.21

Table 4.20

COMPUTATION OF MEAN AND STANDARD DEVIATION FOR MASTER SYNCHRONIZER 1967-1968 MONTHLY CM FIX ACTIONS

CM Fix Actions	m	f	fm	$\lvert m-\bar{x}\rvert$	$f\lvert m-\bar{x}\rvert$	$f(m-\bar{x})^2$
0-0.99	0.5	10	5.0	1.62	16.2	26.24
1.0-1.99	1.5	6	9.0	0.62	3.72	2.31
2.0-2.99	2.5	2	5.0	0.28	0.76	0.29
3.0-3.99	3.5	3	10.5	1.38	4.14	5.71
4.0-4.99	4.5	1	4.5	2.38	2.38	5.66
5.0-5.99	5.5	0	0	3.38	0	0
6.0-6.99	6.5	0	0	4.38	0	0
7.0-7.99	7.5	1	7.5	5.38	5.38	28.94
8.0-8.99	8.5	0	0	6.38	0	0
9.0-9.99	9.5	1	9.5	7.38	7.38	54.46
Sum	n/a	24	51.0	33.28	39.96	123.61

Mean = $\bar{x}$ = 2.12

Average Deviation = A.D. - 1.66

Sample Standard Deviation = s = ± 2.27

Median = Md. = ± 1.33

Coefficient of Skewness = 1.04 (positively skewed)

Coefficient of Variation = $\frac{s}{\bar{x}}$= 1.07

Source: Calculated from Table 4.19.

Table 4.21

FITTING A NORMAL CURVE TO MASTER SYNCHRONIZER CM FIX ACTION HISTOGRAM[1]

(x) classes	midpoint	Frequency (x) observed for (m)	$z = \frac{m-\bar{x}}{s}$	area	Hypothetical (f) normally distributed on (m)
0.0-0.99	0.5	10	-0.71	.2611	3.278
1.0-1.99	1.5	6	-0.27	.1064	4.066
2.0-2.99	2.5	2	0.17	.0675	4.156
3.0-3.99	3.5	3	0.65	.2422	3.414
4.0-4.99	4.5	1	1.05	.3531	2.430
5.0-5.99	5.5	0	1.49	.4319	1.390
6.0-6.99	6.5	0	1.93	.4732	0.655
7.0-7.99	7.5	1	2.37	.4911	0.255
8.0-8.99	8.5	0	2.81	.4975	0.081
9.0-9.99	9.5	1	3.25	.4990	0.033

(x) = Monthly CM Fix Actions

Mean = $\bar{x}$ = 2.12 = Hypothetical frequency of 4.216

n = 24, s = $\pm$2.27, i = 1, N = 39

Source: Calculated from PCN Reports No. 5, Part 1, Section 1. PCN 44115A, "System & Component Discrepancy Summary," 1967-1968.

[1]See Table 4.3 notes for explanation to above table.

Table 4.22(a)

SUMMARY OF EQUIPMENT SUBSYSTEM CHARACTERISTICS

Equipment Categories	(x) Mean	Coefficient of Skewness	Sample Size(N)	(+/-) Standard Deviation	Coefficient of Variation
Combined 13 Subsystems	725.00	-.417	17400	180.00	.248
MIP	44.58	.010	1070	11.72	.263
SCO	32.50	.496	780	15.10	.465
RADAR	408.00	-.333	9800	126.00	.309
CAMEG	6.00	1.040	144	4.97	.828
Tac Dis.	13.50	.185	324	8.11	.601
Master Sync	2.12	1.070	39	2.27	1.070

4.22(b)

SUMMARY RANK INFORMATION ON EQUIPMENT SUBSYSTEMS

Equipment Categories	(x) Mean	Skewness +	Skewness -	Sample Size(N)	Standard Deviation	Coefficient of Variation
Combined 13 Subsystems	1		6	1	1	7
MIP	3	7		3	4	6
SCO	4	3		4	3	4
RADAR	2		5	2	2	5
CAMEG	6	2		6	6	2
Tac Disp.	5	4		5	5	3
Master Sync	7	1		7	7	1

*Note - In all categories the larger number received 1st rank and the lowest received 7th rank.

Source: Calculated from Tables 4.1 - 4.21.

Summary

Sample statistics presented in this chapter included the aggregate corrective maintenance fix actions at BMEWS (Alaska) for the past two years ending December 31, 1968. The total number sampled (17,400) represented approximately 30 percent of total CM fix actions at BMEWS installations throughout the world for the U.S.A.F. over the same two year period. Stratification of the parent population excluded the "classified" equipment sub groups, however, this subpopulation represented a negligible percentage of the total maintenance actions.

Statistics used in the analysis were obtained from the Air Force Product Control Number Reports and RCA's Evaluation Charts of the Subsystems. These two sources are the end product reports of the AFM 66-1 Maintenance Data Collection System and represent the most accurate data currently available.

Data were presented in a series of three tables and corresponding figures for each maintenance subsystem, and also for the combined thirteen maintenance groups. The first table of a subsystem lists the statistics observed and their cumulative frequency in percent. Below this table is a figure of the frequency histogram of observed monthly CM fix actions superimposed with a hypothetical normal curve -- this was calculated from the mean and standard deviation statistics of the stratified sample. The second table of a maintenance subsystem contains the resulting characteristics of the subsystem frequency distribution. These include the arithmetic mean, average deviation, standard deviation, median, coefficient of skewness and coefficient of variation. The third table in the series contains the calculations required for the hypothetical frequency normally distributed about the midpoint interval of CM fix actions.

Summary Findings of Chapter

(1) A visual inspection of the sub group CM frequency distribution figures show that some lower control limits are in a negative CM fix action area. The concept of a negative CM fix action is immediately rejected and the normal "fit" is considered inappropriate.

(2) Sixty-seven percent (SCO, CAMEG, Tactical Displays and Master Synchronizer) of the subsystems did not exhibit the characterisitcs of a normal frequency distribution and control limits based on these distributions have no statistical significance.

(3) Observed CM fix actions for the Master Synchronizer sub group were either one or none for 16 of the 24 monthly periods sampled -- this subsystem should be integrated within a larger subsystem for future analysis.

(4) The subsystems that are essentially solid state equipment groups (Master Synchronizer, CAMEG and SCO) have the greatest skewness.

(5) The subsystems that are essentially electro-mechanical equipment groups (MIP, RADAR and Tactical Displays) have the least skewness.

(6) Low skewness overall is a result of unreliable aggregates, i.e., individual equipment sub groups are badly skewed but the sums of the positives and the negatives are offsetting each other.

V

PREVENTIVE MAINTENANCE

Theoretical Foundations

The United States Air Force definition of preventive maintenance (PM) is:

> The care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur of before they develop into major defects.[1]

This definition is in general agreement with most commercial concepts and applications.[2]

The major premise of the Preventive Maintenance program study was that PM and Corrective Maintenance (CM) are interdependent of each other. It was expected on an a priori basis that as the PM labor hours increased, the CM fix actions would decrease. (See general tradeoff sketch, Figure 5.1).[3]

It was decided that in this study approach we use a statistical method supporting this proposition that CM would be inversely to PM,

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[1]U.S. Air Force Glossary of Standardized Terms, AFM 11-1, October 1968, Department of the Air Force, (unclassified).

[2]R.E. Barlow and L.C. Hunter, Operations Research,"Optimum Preventive Maintenance Policies," VIII,8 (1960) 90-100.

[3]A.S. Goldman and T.B. Slattery, Maintainability (New York: John Wiley & Sons Inc., 1964), 71-90.

It may be expressed broadly as:

$$CM = \frac{1}{PM} \qquad (1)$$

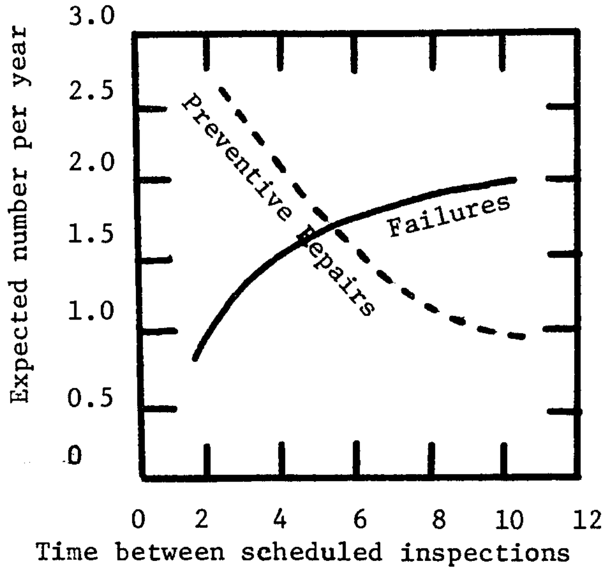
and perhaps by a general linear equation as:

$$CM = a + (b)\,\frac{1}{PM} \qquad (2)$$

In equation (2) PM is represented by units of effort in maintenance and costs, and presumably when these costs are "efficient."

This study suggested that, due to interdependency of CM to PM and possible lead-lag conditions, an increase in PM in some time period could lead to a decrease in CM at some further time period, or that:

Figure 5.1
Deterioration and Failure
Characteristics



Source: Goldman, II, 85.

$$CM = f\left(a + b\,\frac{1}{PM_{t-1}} + c\,\frac{1}{PM_{t-2}} \ldots\ldots_{t-n}\right) \qquad (3)$$

where current period (defined as a month in this report) is labeled t, and the prior period (or month) t-1.

And perhaps by a general linear equation as:

$$CM_t = a + b\,\frac{1}{PM_{t-1}} \qquad (4)$$

A General Hypothesis

The statistical methods which support equations (2) and (4) are a series of simple regression analysis runs. The data sources were the monthly A.F. Product Control Number printouts (PCN 44144A Report No. 4, Part 1, Group 1, 1967-68) and RCAS management evaluation charts. Labor hours were used for the independent variable and hence represent a measure of cost "effort". It was decided to use CM fix actions, rather than CM labor hours, as the dependent variable. CM fix actions could be cross-checked on both the PCN Reports and the management evaluation charts, and hereby decrease the chance of sampling errors.[4]

Initial Overall Findings

If CM and PM are actually related, one would expect that such regression lines would be negatively sloped with a correlation coefficient of greater than 0.50. The results of the first regression run (Chart 5.2. and Table 5.6) reflected that the regression line in $Yc_1 = a + bX$ was: $a = 743$ $b = -0.00836$ (approximately a horizontal line). Correlation between PM and CM was for all practical purposes non-existent with a correlation coefficient of 0.01538. A standard error of prediction of $\pm$ 197 about $(a + bX)$ was also unacceptable. Therefore, a mathematical model using PM as the proxy to CM for workload planning would be useless using this data.

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4 *Ibid.*, Appendix A, p. 205.

A second computer run was calculated using the PM labor hours as a causal variable the CM fix actions, with a time lag of one month inserted from inspection of the PM-CM Seasonal and trend series (Chart 5.1). The following results of the regression analysis run No. #2:

$$\bar{X} = 2141 \text{ labor hours/mo.}$$

$$\bar{Y} = 718 \text{ CM fix actions/mo.}$$

$$Yc_2 = 686 = 0.01498X \qquad (5)$$

$$r = 0.02656$$

$$Sy.x = \pm 204 \text{ CM fix actions/month}$$

Generally, this did not support the general hypothesis of a causal PM-CM relationship.

The clear statistical inference of a type I error (the error made in rejecting a hypothesis when it is true) now presented itself. Again on an a priori basis, the data were closely re-examined. By visual inspection of the worksheets and the scatter diagrams, it was discovered the months with the greatest variance were winter months. This was also corroborated by the results of the seasonal time series analysis as shown in Chart 5.1, Tables 5.1 and 5.2. A third run Chart 5.4, Tables 5.5 and 5.6, was calculated, again using the PM labor hours as a causal variable to the CM fix actions -- this time the winter months of October through February were excluded. The results of this run were as follows:

$\bar{X}$ = 2281 labor hours/month

$\bar{Y}$ = 808 PM fix actions/month

Yc3 = 1182 - 0.16388X

r = 0.461

Sy.x = -131 CM fix actions/month

By comparison to prior trials, this experiment was a vast improvement and entirely plausible. Statistically superior, the relationship remains very "partial" highly variable, i.e., scattered.

Table 5.1

CM SEASONAL ANALYSIS

$$\text{Index Number} = \text{IN} = \frac{X_i}{\sum_{i=1}^{12} X_i \div n} \times 100$$

1967

Jan.	Feb.	March	April	May	June
73.42	101.63	109.09	102.91	107.69	93.24
July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
108.97	126.34	99.77	98.14	78.09	101.51

1968

Jan.	Feb.	March	April	May	June
66.31	53.03	78.90	82.05	84.84	89.86
July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
95.68	94.36	63.87	48.60	36.36	54.43

Source: Calculated from Table 5.3

TAble 5.2

PM SEASONAL ANALYSIS

$$\text{Index Number} = \text{IN} = \frac{X_i}{\sum_{i=1}^{12} X_i \div n} \times 100$$

1967

Jan.	Feb.	March	April	May	June
96.32	103.08	102.73	93.30	94.64	139.03
July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
107.89	88.18	104.76	96.32	83.42	90.62

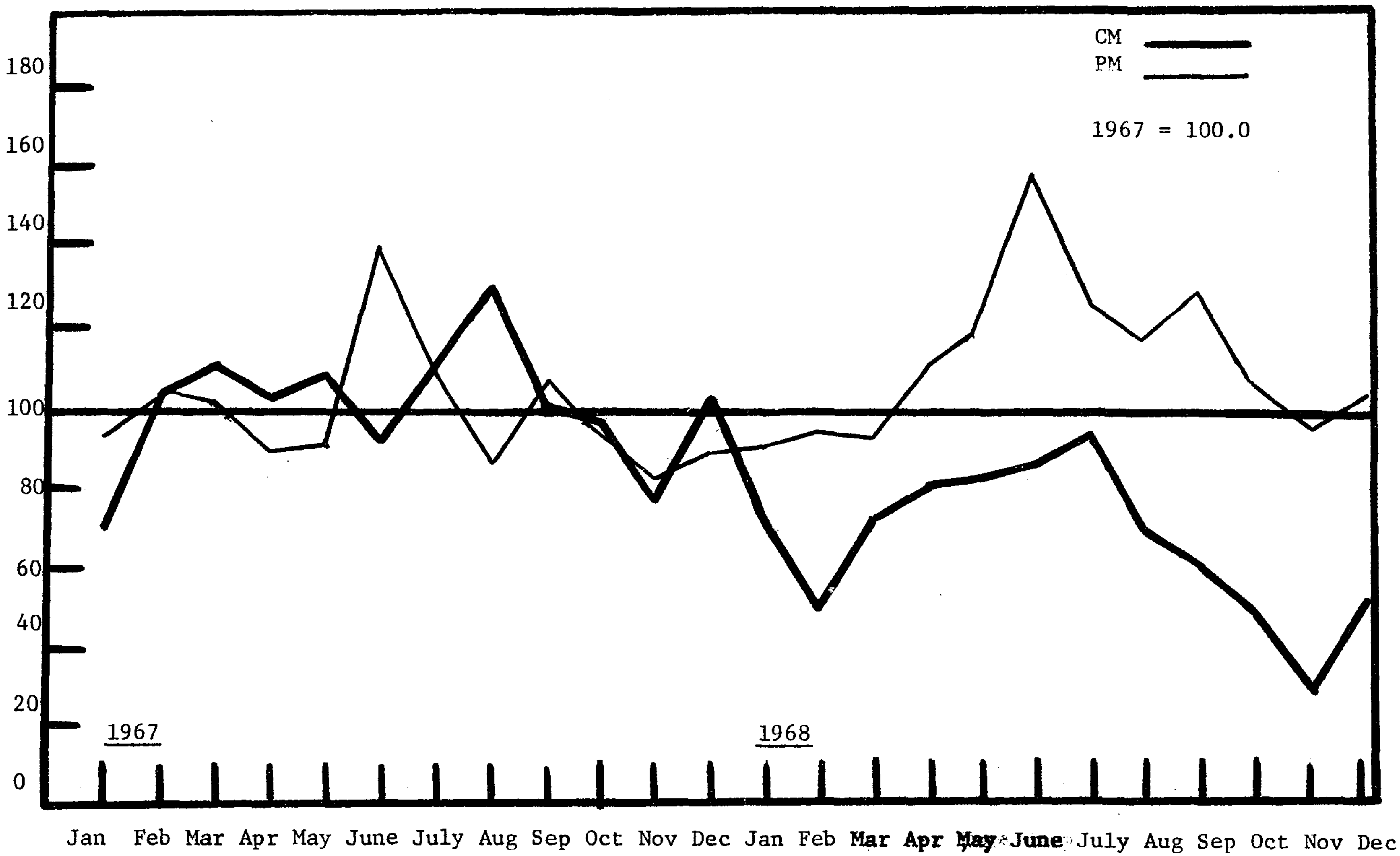
1968

Jan.	Feb.	March	April	May	June
92.70	96.57	95.58	110.43	121.10	159.98
July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
124.23	117.48	126.22	106.06	96.72	103.92

Source: Calculated from Table 5.3

Figure 5.2

PM - CM Seasonal Analysis



Source: Tables 5.1 and 5.2

Table 5.3

WORKSHEET FOR SIMPLE REGRESSION ANALYSIS NO. 1

1967 Month	PM Labor Hours X	CM Fix Actions Y	X^2	Y^2	XY	$\bar{\bar{Y}}$	$Y-\bar{\bar{Y}}$	$(Y-\bar{\bar{Y}})^2$
Jan.	1940	630	3763600	396900	1222200	727	-97	9409
Feb.	2076	872	4309776	760384	1810272	726	146	21316
Mar.	2069	936	4280761	876096	1936584	726	210	44100
Apr.	1879	883	3530641	779689	1659157	727	156	24366
May	1906	924	3632836	853776	1761144	727	197	38809
June	2800	800	7840000	640000	2240000	720	80	6400
July	2173	935	4721929	824225	2031755	725	210	44100
Aug.	1776	1084	3154176	1175056	1925184	728	356	126736
Sept.	2110	856	4452100	732736	1806160	725	131	17161
Oct.	1940	842	3763600	708964	1633480	727	115	13225
Nov.	1680	670	2822400	448900	1125600	729	-59	3481
Dec.	1825	871	3330625	758641	1589575	728	143	20449

Source: U.S.A.F. Monthly Product Control Printouts (PCN 44144A Report No. 4 Part 1, Group I) 1967-1968..... R.C.A. Service Co. Management Evaluation Charts - same period.

Table 5.3 --- (Continued)

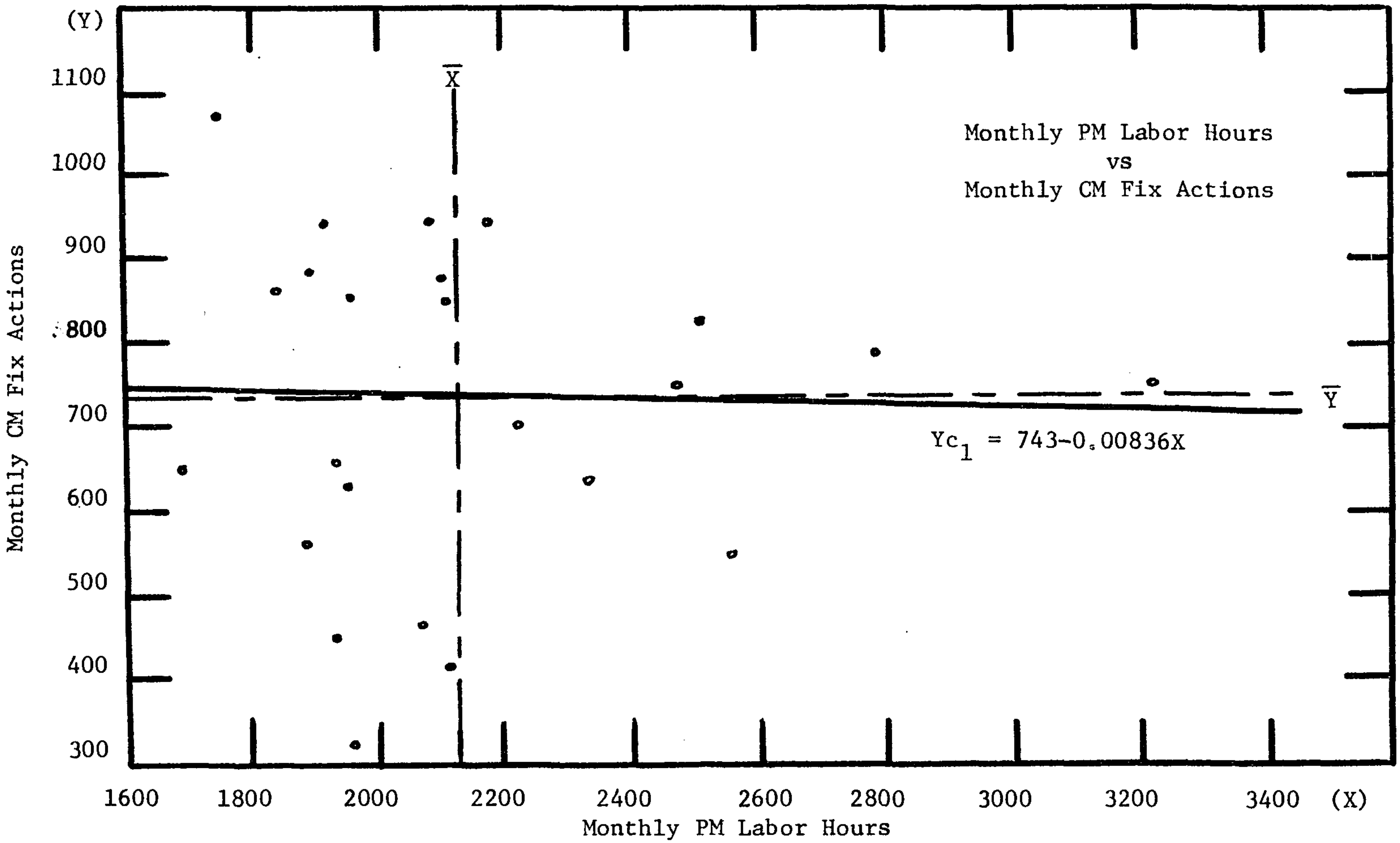
WORKSHEET FOR SIMPLE REGRESSION ANALYSIS NO. 1

	1968 Month	PM Labor Hours X	CM Fix Actions Y	X^2	Y^2	XY	$\bar{\bar{Y}}$	$Y-\bar{\bar{Y}}$	$(Y-\bar{\bar{Y}})^2$
	Jan.	1867	569	3485689	323761	1062323	727	-158	24964
	Feb.	1945	455	378025	207025	884975	727	-272	73984
	Mar.	1925	677	3705625	458329	1303225	727	-50	2500
	Apr.	2224	704	4946176	495616	1565696	724	-20	400
	May	2439	728	5948721	529984	1775592	723	5	25
	June	3222	771	10381284	594441	2484162	716	55	3025
	July	2502	821	6260004	674041	2054142	722	99	9801
	Aug.	2366	638	5597956	407044	1509508	723	-85	7225
	Sept.	2541	548	6456681	300304	1392468	722	-174	30276
	Oct.	2136	417	4562496	173889	890712	725	-308	94864
	Nov.	1948	312	3794704	97344	607776	727	-415	172225
	Dec.	2093	467	4380649	218089	977431	726	-259	67081
TOTALS	24	51382	17410	112905454	13485234	37249121	17404	6	855892

Source: U.S.A.F. Monthly Product Control Printouts (PCN 44144A Report No. 4 Part 1, Group I) 1967-1968..... R.C.A. Service Co. Management Evaluation Charts.

Figure 5.3

REGRESSION RUN NO. 1



Source: Tables 5.3 and 5.6.

Table 5.4

WORKSHEET FOR SIMPLE REGRESSION ANALYSIS NO. 2
(CM LAGS PM BY ONE MONTH)

1967/1968 Month	PM Labor Hours X	CM Fix Actions Y	X^2	Y^2	XY	$\bar{\bar{Y}}$	$Y-\bar{\bar{Y}}$	$(Y-\bar{\bar{Y}})^2$
Jan/Feb	1940	872	3763600	760384	1691680	715	157	24649
Feb/Mar	2076	936	4309776	876096	1943136	717	219	47961
Mar/Apr	2069	883	4280761	779689	1836927	717	166	27556
Apr/May	1879	924	3530641	853776	1736196	714	210	44100
May/June	1906	800	3632836	640000	1524800	714	86	7396
June/July	2800	935	7840000	874225	2618000	728	207	42849
July/Aug	2173	1084	4721929	1175056	2355532	718	366	111956
Aug/Sept	1776	856	3154176	732736	1520256	712	144	20736
Sept/Oct	2110	842	4452100	708964	1776620	718	124	15376
Oct/Nov	1940	670	3763600	448900	1299800	715	-45	2025
Nov/Dec	1680	871	2822400	758641	1463280	711	160	25600
Dec/Jan	1825	569	3330625	323761	1038425	713	-144	20736

Table 5.4 (continued)

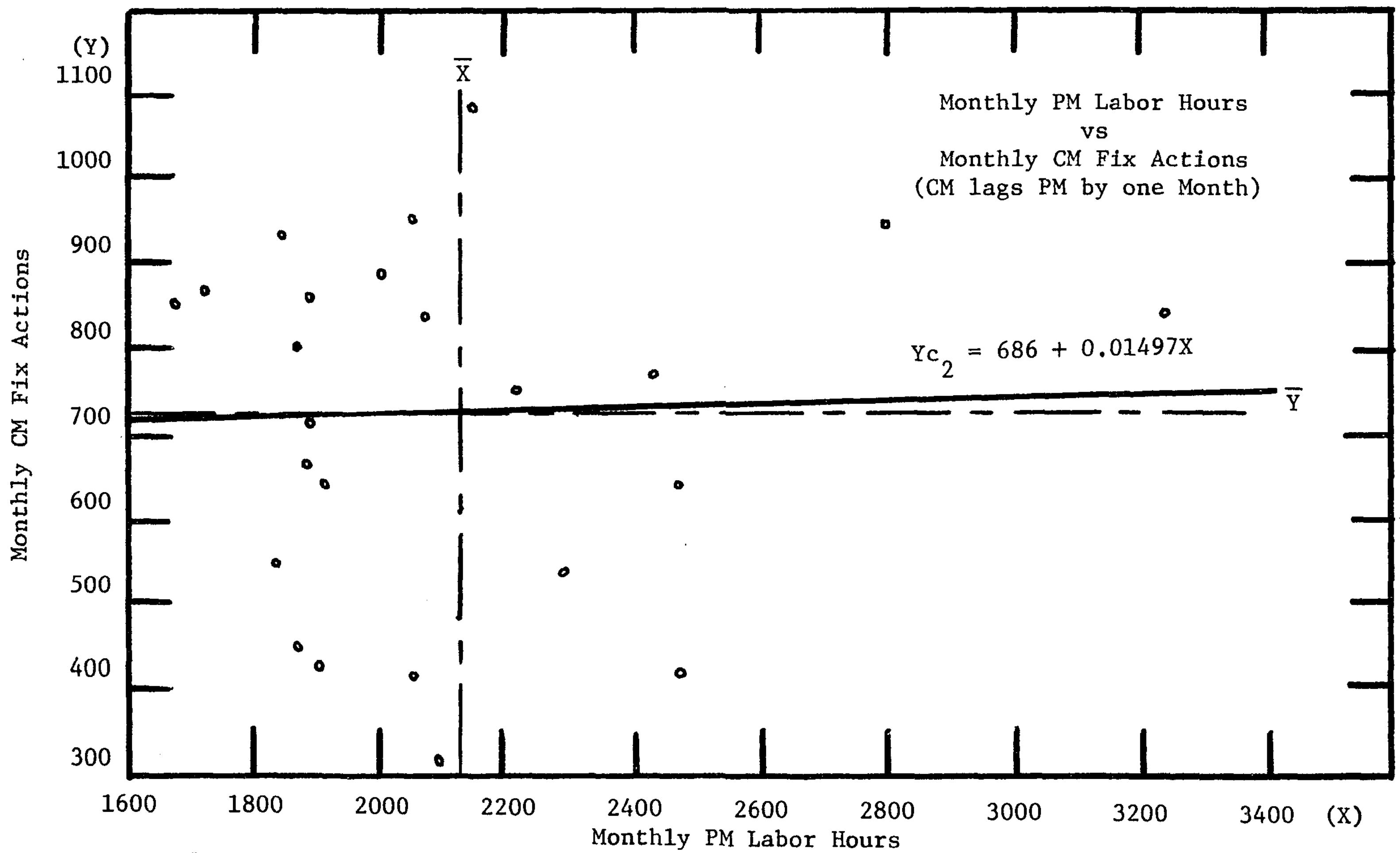
WORKSHEET FOR SIMPLE REGRESSION ANALYSIS NO. 2
(CM LAGS PM BY ONE MONTH)

1967/1968 Month	PM Labor Hours X	CM Fix Actions Y	X^2	Y^2	XY	$\bar{\bar{Y}}$	$Y-\bar{\bar{Y}}$	$(Y-\bar{\bar{Y}})^2$
Jan/Feb	1867	455	3485689	207025	849485	714	-259	67081
Feb/Mar	1945	677	3783025	458329	1316765	715	-38	1444
Mar/Apr	1925	704	3705625	495616	1355200	715	-11	121
Apr/May	2224	728	4946176	529984	1619072	719	9	81
May/June	2439	771	5948721	594441	1880469	722	49	2401
June/July	3222	821	10381284	674041	2645262	734	87	7569
July/Aug	2502	638	6260004	407004	1596276	723	-85	7225
Aug/Sept	2366	548	5597956	300304	1296568	721	-173	29929
Sept/Oct	2541	417	6456681	173889	1059597	724	-307	94249
Oct/Nov	2136	312	4562496	97344	666432	717	-405	164025
Nov/Dec	1948	467	3794704	218089	909716	715	-248	61504
Dec/Jan	2093	448	4380649	200704	937664	717	-269	72361
Totals	51382	17228	112905454	13289038	36927158	17228	0	920930

Source: Calculated from Table 5.3 and PCN 44144A, Jan., 1969.

Figure 5.4

REGRESSION RUN NO. 2



Source: Tables 5.4 and 5.6.

Table 5.5

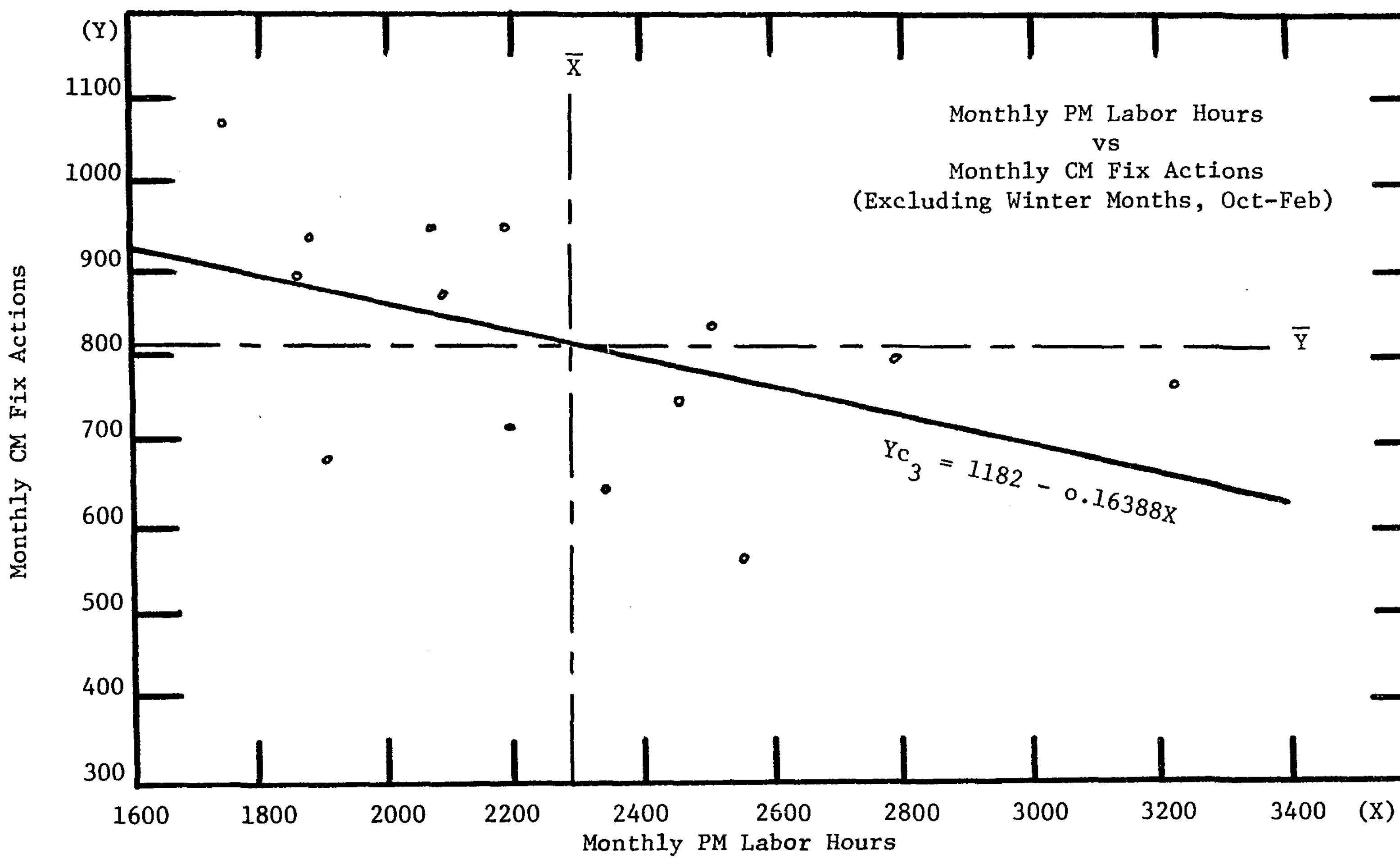
WORKSHEET FOR SIMPLE REGRESSION ANALYSIS NO. 3
(Excluding Winter Months Oct.-Feb.)

	Month	PM Labor Hours X	CM Fix Actions Y	X^2	Y^2	XY	$\bar{\bar{Y}}$	$Y-\bar{\bar{Y}}$	$(Y-\bar{\bar{Y}})^2$
1967	Mar.	2069	936	4820761	876096	1936584	843	93	8649
	Apr.	1879	883	3530641	779689	1659157	874	9	81
	May	1906	924	3632836	853776	1761144	870	54	2916
	June	2800	800	7840000	640000	2240000	723	77	5929
	July	2173	935	4721929	874225	2031755	826	109	11881
	Aug.	1776	1084	3154176	1175056	1925184	891	193	37249
	Sept.	2110	856	4452100	732736	1806160	836	20	400
1968	Mar.	1925	677	3705625	458329	1303225	867	-190	36100
	Apr.	2224	704	4946176	495616	1565696	817	-113	12769
	May	2439	728	4948721	529984	1775592	782	-54	2916
	June	3222	771	10381284	594441	2484162	654	117	13689
	July	2502	821	6260004	674041	2054142	772	49	2401
	Aug.	2366	638	5597956	407044	1509508	794	-156	24336
	Sept.	2541	548	6456681	300304	1392468	765	-217	47089
TOTALS	14	31932	11305	74908890	9391337	25444777	11316	-9	206405

Source: Calculated from Table 5.3

Figure 5.5

REGRESSION RUN NO. 3



Source: Tables 5.5 and 5.6.

TABLE 5.6

RECAPITULATION OF REGRESSION ANALYSES RESULTS

Run No.	Variables	PM Average Labor Hours	CM Average CM Fix Actions	Regression Equation	Correlation Coefficient	Standard Error of Prediction
No.1	PM labor hours per month as a causal variable to CM fix action per month 1967-1968	2141	725	$Yc_1=743-0.00836X$	0.015383	$\pm$ 197 about Yc_1
No. 2	PM labor hours per month as a causal variable to CM fix actions per month (CM lags PM by one month) 1967 - Jan. 1969	2141	718	$Yc_2=686+0.01498X$	0.02656	$\pm$ 204 about Yc_2
No. 3	PM labor hours per month as a causal variable to CM fix actions per month (Excluding Winter Months) 1967-1968	2281	808	$Yc_3=1182-0.16388X$	0.4610	$\pm$131 about Yc_3

Source: Calculated from Tables 5.1, 5.2 and 5.3.

Planned Replacement in Preventive Maintenance

Planned replacement decisions are established by the AFM66-1 Program as the "Time Change Item Program." It is based upon contractor experience and historical data obtained through the years that the equipment has been in operation.[5] Those items which exhibit the characteristics of a "*fixed service life expectancy*", are economically feasible to repair or have serious degrading effects on operational equipment are periodically replaced (e.g., motors, gears, bearings, batteries, etc.).[6] This planned replacement policy is gaining widespread acceptance at both military and commercial installations. The extent to which it is utilized is dependent upon the mission objectives. AFM 66-1 Time Change Item Program has not been fully automated and there is limited information on the efficiency of its operation. The frequency of replacements are dependent upon a screening of "raw" data form information by clerical personnel and hence subject to human errors.

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[5] R.E. Barlow and F. Proscham, Planned Replacement, Sylvania Electronic Defense Laboratories, Technical Memo No. EDL-M296, 1960.

[6] Howard L. Timms, The Production Function in Business, (Homewood, Illinois: Richard D. Irwin, Inc., 1966), 378-9.

Summary

(1) From the various sections of this chapter, it is apparent that an increase in PM should result generally in a decrease in CM or conversely that a decrease in PM should result in an increase in CM -- this was not substantiated by the evidence.

(2) The results of the first regression run chosen to support this hypothesis, where PM (labor hours) was the independent variable to CM (fix actions), showed that CM was nearly a monthly constant regardless of PM effort expended.

(3) The second regression run, where the CM dependent variable was time lagged one month, resulted in an increase of CM for an increase in PM -- this directly contradicts the general hypothesis in spite of its apparently sound reasoning. Therefore, a "special" condition of data ommission was attempted. Spot checks of a subsystem have shown the data to be questionable at times.[7] Visual inspection of worksheets and charts of the first two regression runs and the seasonal analysis show that the winter months have the greatest variance.

(4) At this stage of the study several alternatives remained --

a. The general hypothesis is incorrect.

b. The PM program is grossly inefficient.[8]

c. The sampled data were bias, i.e., incorrect.

---

[7] See "Inconsistencies in Data Reporting" in Appendix C.

[8] The BMEWS overall system has shown a high degree of performance. System availability and operating records as shown in Appendix C logically minimize the probability or validity of this alternative.

d. Data proxies were erroneous, incorrectly reported or misinterpreted.

e. A combination of any or all of the above.

(5) Data for the winter months were excluded and a third regression run was computed. Results of this run partially supported the general hypothesis.

Based on provisional evidence it is reasonably apparent that there is partial correlation between PM and CM, but that a precise mathematical delineation is not appropriate without much further investigation. Obviously other factors, perhaps integral actions within CM and PM, are more relevant and causal than the independent variables (e.g., mission objectives, age and design reliability of equipment, human factors, budget methods, seasonal variations, subsystem equipment configuration, etc.). The author's interpretation of these results of regression analysis is that the input data for the winter months were in fact incorrectly reported. In other words the information system for maintenance control was not reliable.

If the input data could be improved, other regression analyses could be performed that would aid in estimating the effectiveness of the PM/CM program. Benefits of workable mathematical models would be the continual improvement of the entire PM decision rules by refining the runs to end items -- this may be accomplished by reducing the PM labor hours on the least correlating end items. A breakdown of the equipment into electro-mechanical and electrical categories could also be very revealing. On the basis of raw data observed, the solid state equipment groups appear to require very little PM and thus is a less fruitful area for additional study.

VI

SUMMARY

Maintenance Data Collection

This research project began with a detailed description of the A.F. MDC system used at BMEWS in the Alaskan Interior. A flow chart was introduced depicting the maintenance management data forms flow and disposition of the reparable items removed for maintenance. Explanation of the data forms used and the processing of them were complemented through the use of a large sample of computer flow charts and special examples cited in Appendix A -- some of the maintenance decision rules involved were described also. Analysis of the MDC system has suggested two necessary improvements, and they are listed as:

(1) Most of the management control effort is directed toward accuracy of information in the forms. This overall study has shown that errors of omission rather than errors of commission are the greater management problems. The work center supervisor control block (Figure 2.1) is the logical stage at which this reporting should be improved.

(2) Block F of the AFTO 349 form (Figure A-15) presents a human factor variable in that it represents a human judgement for over 900 different codes for the "How Mal" of which most are related to aircraft malfunctions -- the work center should delineate only those codes applicable to the expected equipment faults.[1]

---

[1] This would not violate rules of the Standard Data System (SDS) as defined in the Glossary.

Method of Research and AFM 66-1

The design and critique of the overall reporting system and the areas of special interest to the study were presented. Purpose, format and explanations of the basic reports were covered in detail. Examples of the nine PCN reports were also included in Appendix B. A study of the control concepts and applications of the results of the AFM 66-1 Maintenance Management Program introduced the upper control limit decision rule as the overriding statistical method used by maintenance analysts. A basic rule established in the program is that analysis would be initiated on an equipment group whenever the upper control limit is exceeded. A decided improvement would be to initiate analysis whenever upper or lower control limits are exceeded. A low monthly CM fix action total might indicate a breakdown of the reporting system and would aid in checking for data omission problems referred to in the paragraph above.

Statistical Analysis

The statistical analysis was developed and predicated upon some basic provisions regarding the relationship between the stratified samples and the parent population. Data sources were presented and descriptions of the tables were outlined. Observed monthly CM fix actions frequency histograms of the combined thirteen subsystems were constructed and superimposed by hypothetical normal curves. Statistics and characteristics of the stratified samples were summarized and results of the analysis were as follows:

(1) Visual inspection of the sybsystems CM frequency distribution sufficed to show that the "fit" on the majority of them were bad.

(2) It was shown that some heterogeneous equipment groups are being processed as homogeneous groups for analytical statistical purposes. The subsystems (end items) with the best "fit" have a good mix consisting of electromechanical and solid state devices, e.g., MIP and RADAR.

(3) Based on the above observation, subsystems: SCO; CAMEG; Tactical Displays and Master Synchronizer should be merged with a RADAR mechanical equipment group into one new subsystem for reporting purposes. This would also correct the problem of some subsystems having too few monthly CM fix actions for statistical analysis.

Preventive Maintenance

A detailed Air Force definition of Preventive Maintenance (supported by commercial references) was introduced as a general hypothesis that monthly PM labor hours would be the proxy for monthly CM fix actions. A straight line simple regression run with PM monthly labor hours as the independent variable and CM fix actions as the dependent variable did not support this proposition. A second run was computed with CM time lagged by one month. The results of this run directly contradicted the general hypothesis in spite of its apparently sound reasoning. On the basis of these results and other a priori evidence, a third run was computed with a "special" condition of data ommission. Results of this run with the winter months exluded partially supported the general hypothesis. General conclusions of this chapter were that other integral factors, e.g., mission objectives, age and design reliability of equipment, human factors, budget methods, seasonal variations, subsystem equipment configuration, etc., perhaps were more relevant and causal than the independent variables. The author's interpretation of the results of the regression analysis is that the input data for the winter months were in fact incorrectly reported. In other words the information system for maintenance control was not reliable.

Overall Findings

The performance evaluation of BMEWS in the Alaskan Interior reflected that the system is attaining a high degree of performance for its primary mission objectives.[2] These objectives, however, occassionally interfere with the efficiency of the computerized maintenance management program (exceptions to the program are allowed during periods of "maximum maintenance efforts"). Human factors, especially in the area of reliable data reporting appear to be influenced by the climatic conditions of the area. The absence-tardiness seasonal trend index of Appendix C support the findings of Chapter V that the data in the winter months should be carefully evaluated -- the basis for this reasoning is that morale should be considered as a function of employee attendance. Special attention to the data reporting and greater reliance placed on the System Automatic Checkout Equipment is required during the winter months. Many of the side benefits of a computerized maintenance management program could not be included within the scope of this report, but it follows that there are some logistic/provisioning problems associated with the usage of bench stock and supply parts caused by the loss of some input data.

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[2]See Appendix C for performance evaluation.

APPENDIX A

General Systems Flow Chart

Source: Adapted from the U.S. Air Force, Automatic Data Processing Systems and Procedures AFM 171-IV, Department of the Air Force, May, 1968 (Unclassified).

APPENDIX A

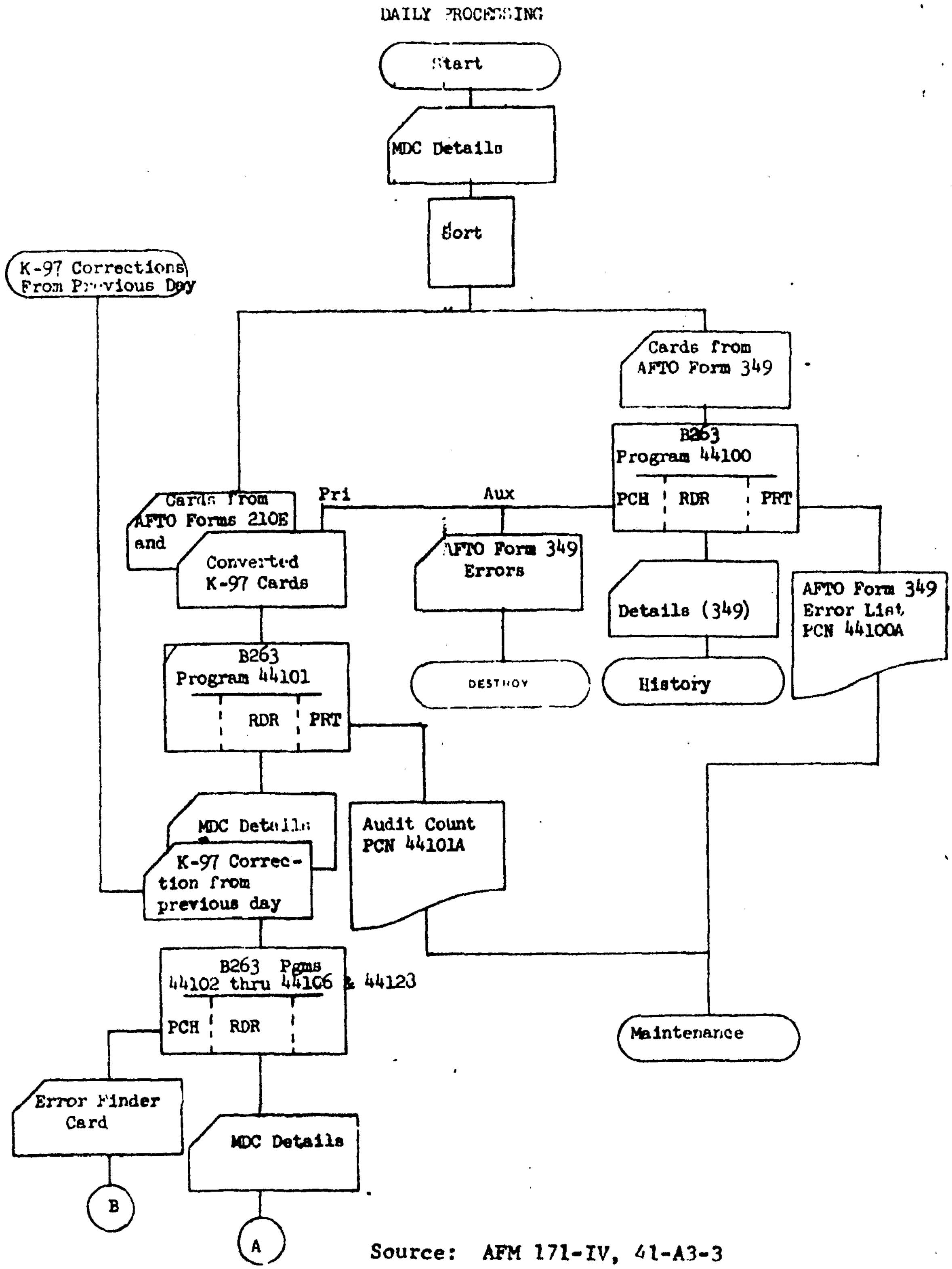
Description of Representative Programs

Figure No.	Program No.	Description
A-1	44100	Reads the merged Master ID Cards and the Detail Cards punched from the Data Form 349's. Edits for valid ID No., if valid converts to and punches a standard K-97 card. If invalid punches an error card to be listed in a subsequent pass.
A-1	44102	Edits the "FSC" and "How Mal" Codes in all MDC Detail Cards. Utilizes punched card input tables which are set up in a memory for use in table lookup function. Errors in the input card cause an Error Finder card to be punched.
A-6	44112	Sequence check, tabulates and summarizes to produce the Monthly Production summary cards to be used in the preparation of the Monthly Labor Hours Summary. Report No. 3.
A-6	44113	Sequence checks, tabulates and accumulates totals for various hour fields.
A-7	44114	Tabulates with minor, intermediate and major totals furnished for units produced and direct labor, and provides totals by type document for each activity. The Data Constant Control card determines which part of the report is being run and changes the controls and headings accordingly.
A-8	44115	Detail lists with subminor, minor, intermediate and major totals furnished for hours and units produced. Provides total type document count by each activity. The Data Constant Control card determines which part of the report is being run and changes the headings accordingly.

Figure No.	Program No.	Description
A-13	44122	Sequence checks and lists with total furnished for units produced with a listing of all bit and pieces that failed during the month.

DAILY PROCESSING OF DATA FORMS APPENDIX A

Figure A-1

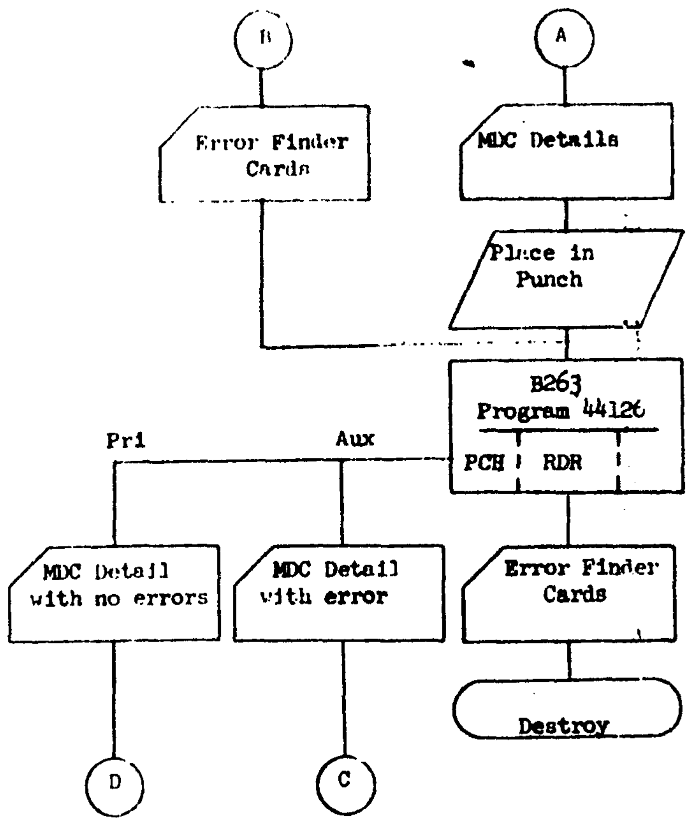


Source: AFM 171-IV, 41-A3-3

DAILY PROCESSING OF DATA FORMS -- Continued

APPENDIX A -- Continued

Figure A-2

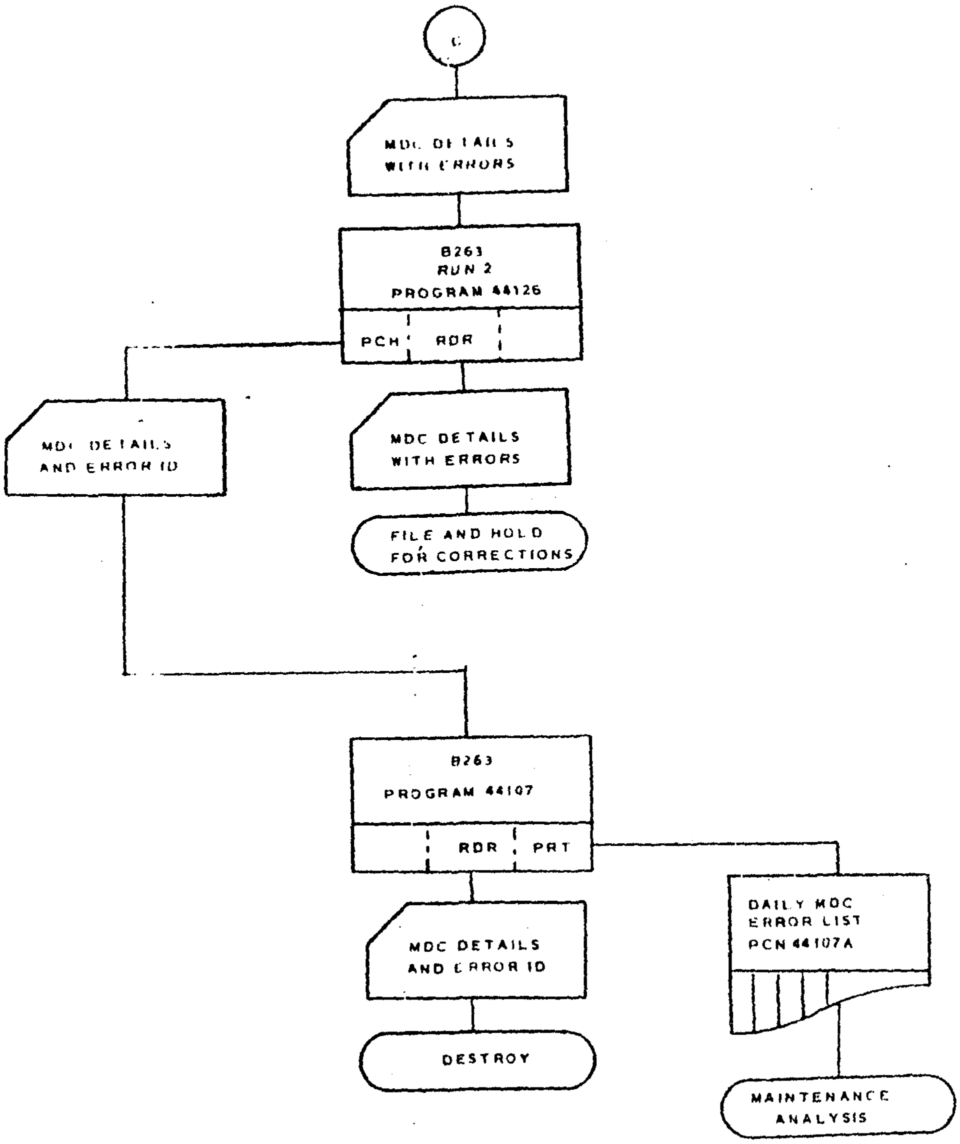


Source: AFM 171-IV, 41-A3-4

DAILY PROCESSING OF DATA FORMS -- Continued

APPENDIX A -- Continued

Figure A-3

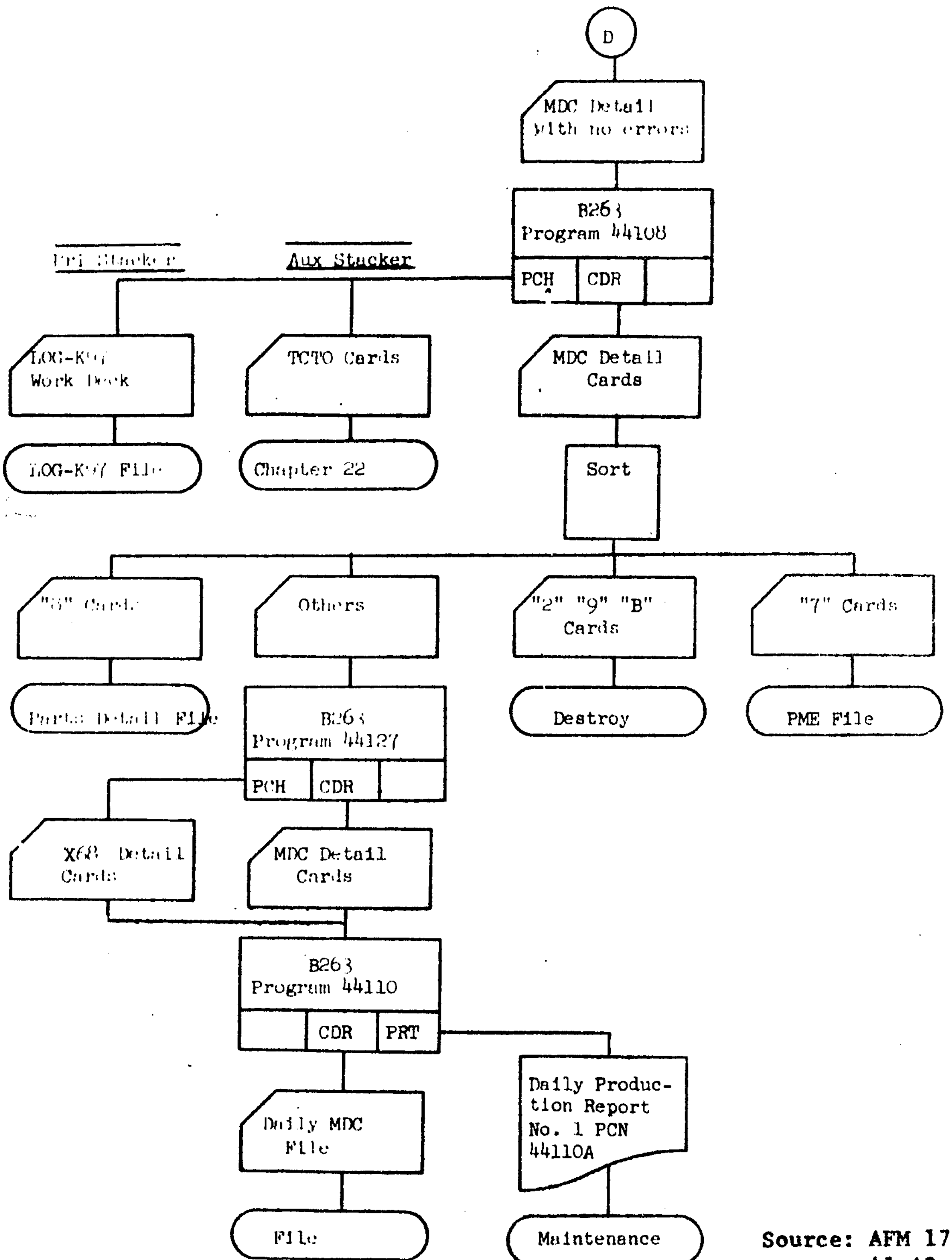


Source: AFM 171-IV, 41-A3-5

DAILY PROCESSING OF DATA FORMS -- <u>Continued</u>

APPENDIX A -- <u>Continued</u>

Figure A-4

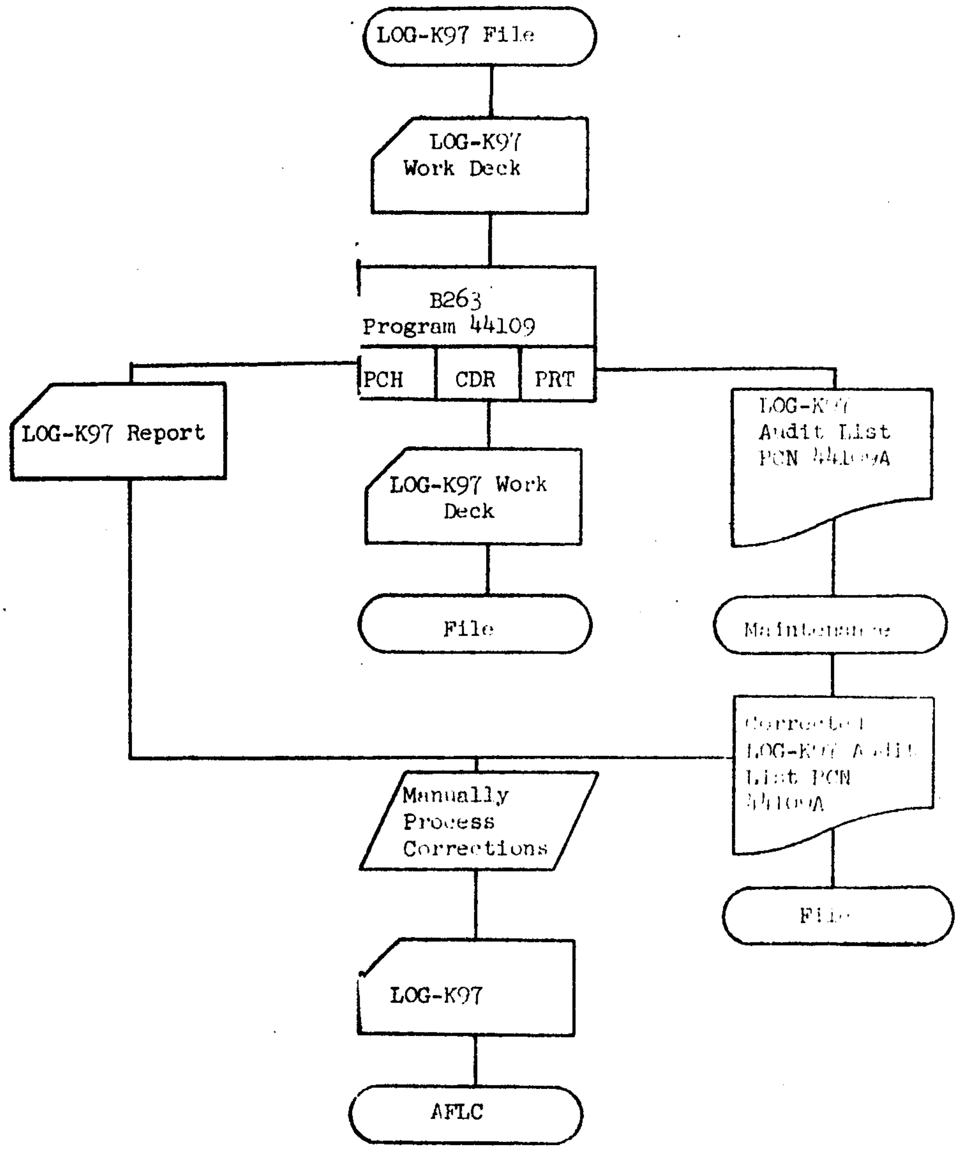


Source: AFM 171-IV,
41-A3-6

LOGISTICS PROCESSING

APPENDIX A -- Continued

Figure A-5

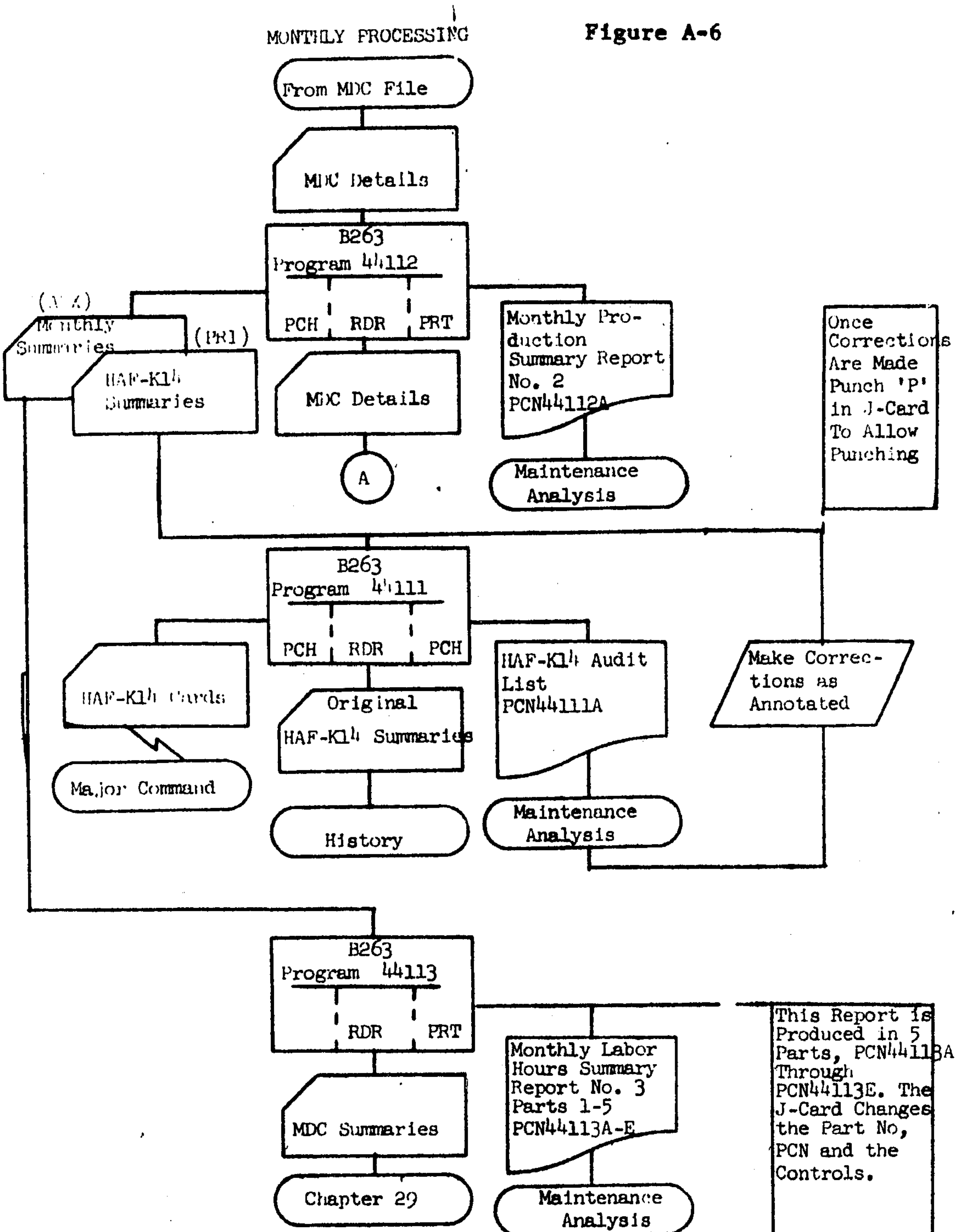


Source: AFM 171-IV, 41-A3-7

MONTHLY PRODUCTION AND LABOR HOURS SUMMARY

APPENDIX A -- Continued

Figure A-6

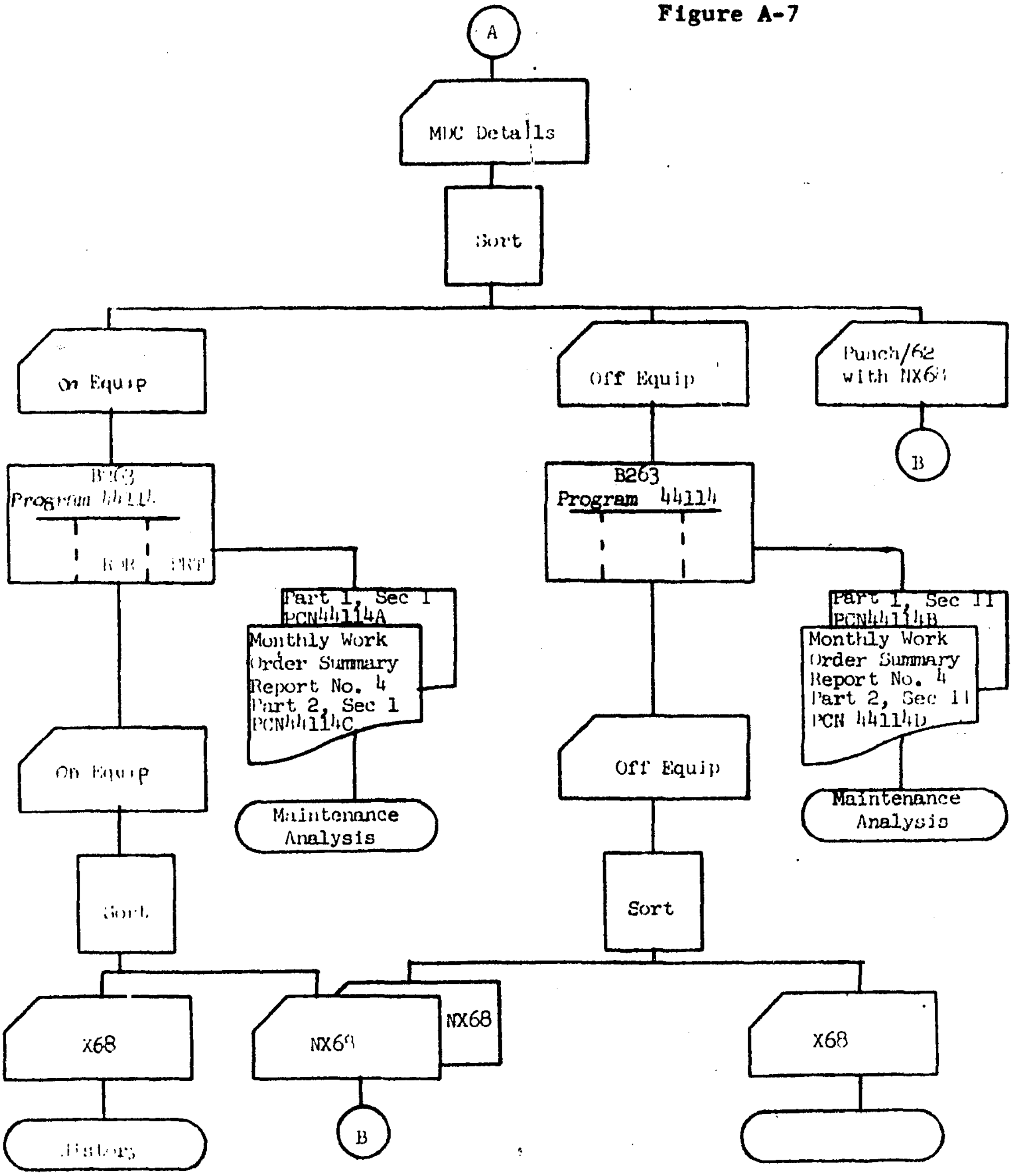


Source: AFM 171-IV, 41-A3-8

MONTHLY WORK ORDER SUMMARY

APPENDIX A -- Continued

Figure A-7

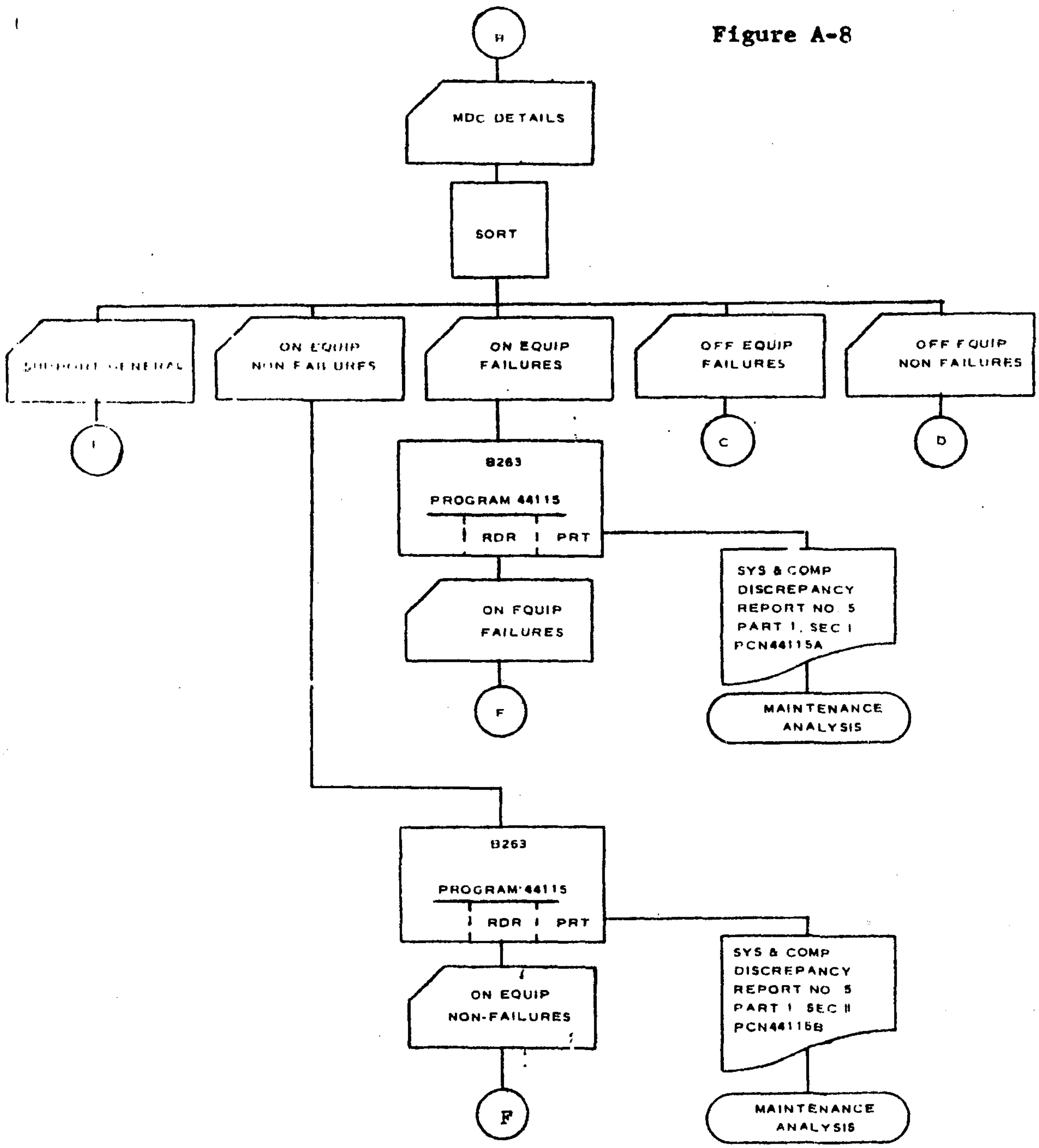


Source: AFM 171-IV, 41-A3-9

SYSTEM AND COMPONENT REPORT SUMMARY

APPENDIX A -- Continued

Figure A-8



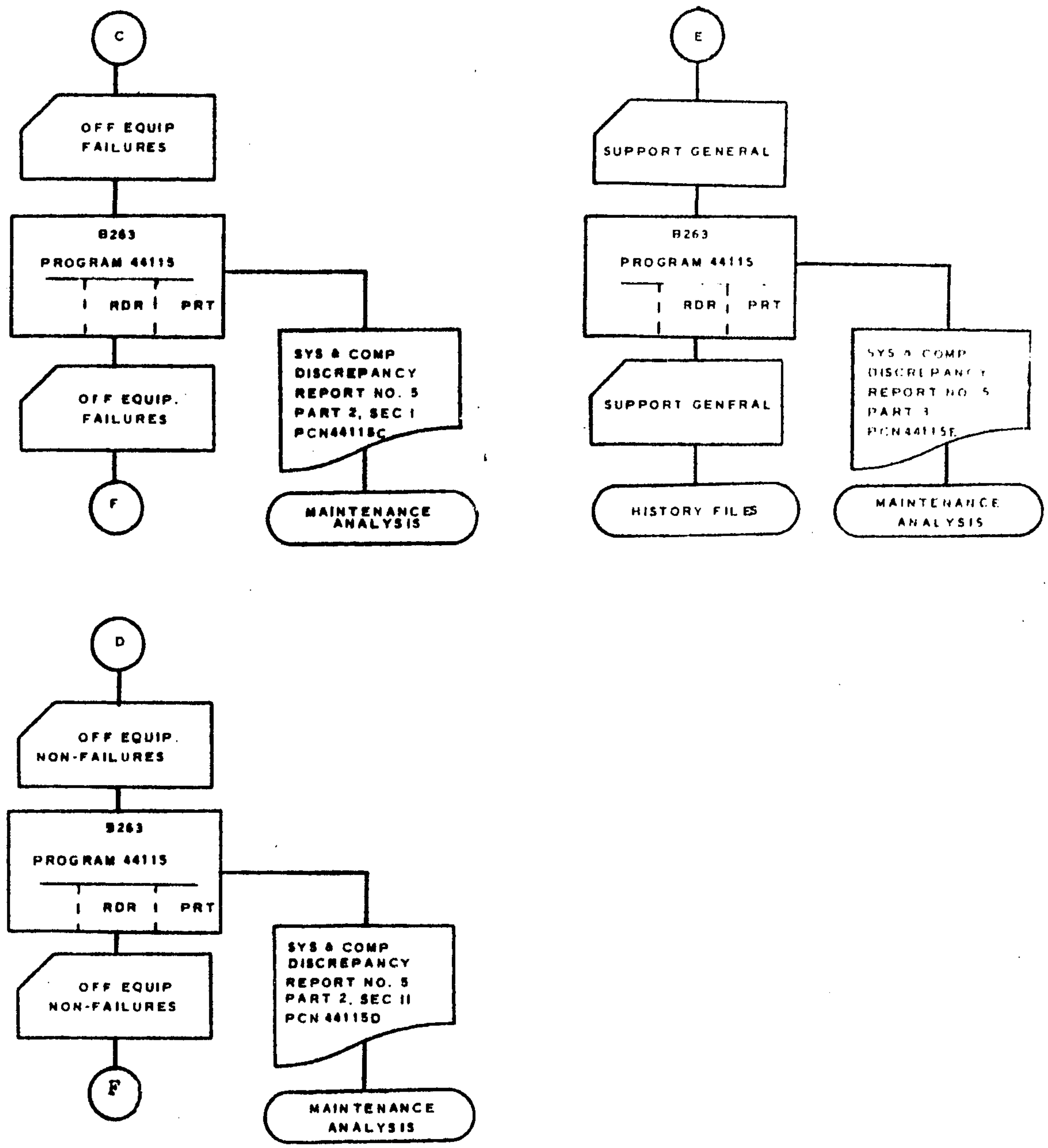
Source: AFM 171-IV, 41-A3-10

APPENDIX A -- Continued

Figure A-9

SYSTEM AND COMPONENT

REPORT SUMMARY

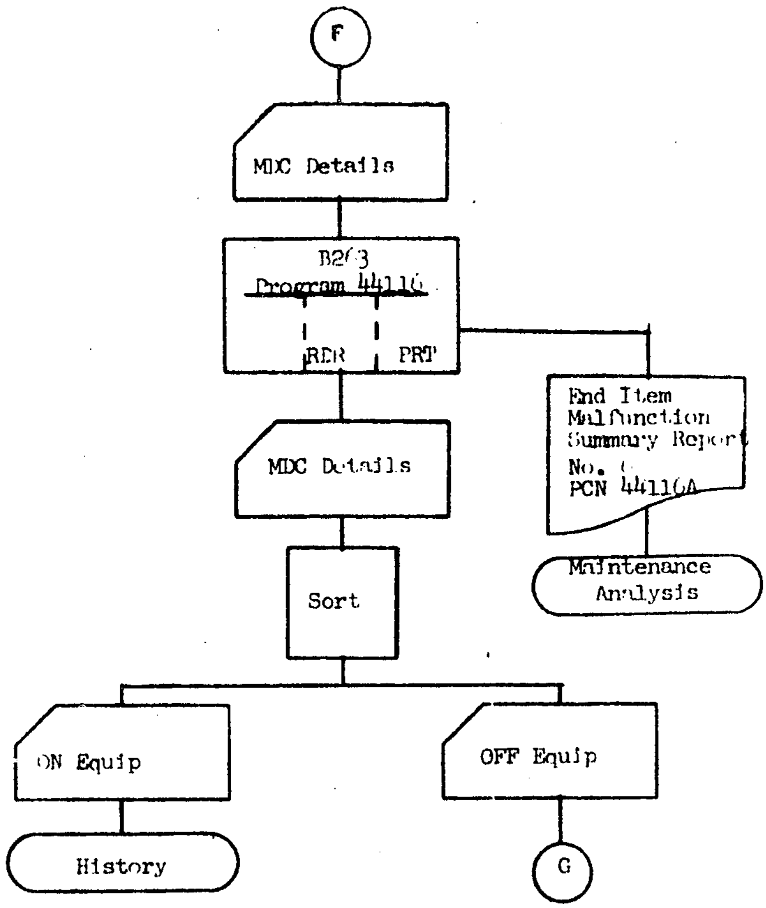


Source: AFM 171-IV, 41-A3-11

END ITEM MALFUNCTION SUMMARY

APPENDIX A -- Continued

Figure A-10

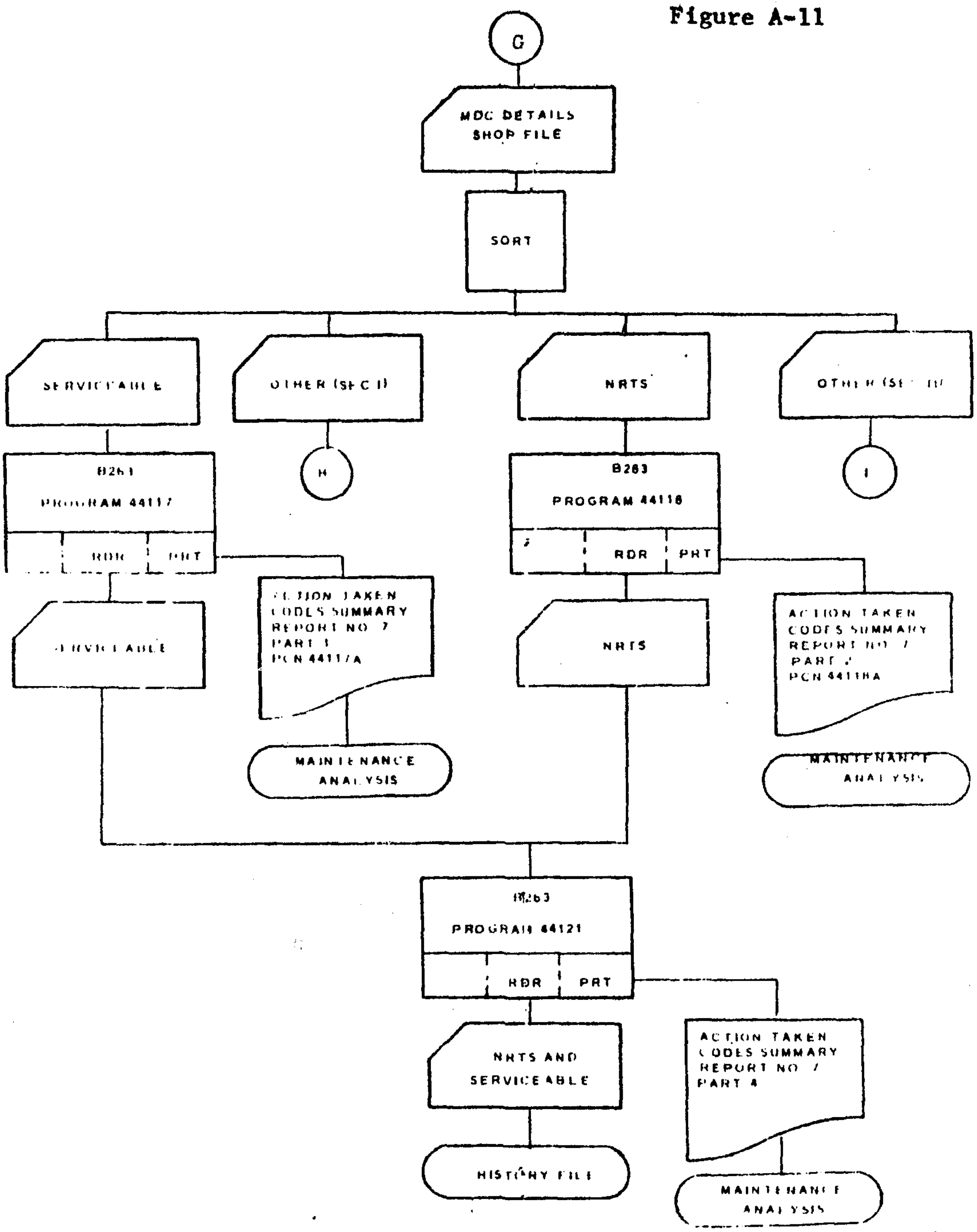


Source: AFM 171-IV, 41-A3-12

ACTION TAKEN CODES SUMMARY

APPENDIX A -- Continued

Figure A-11

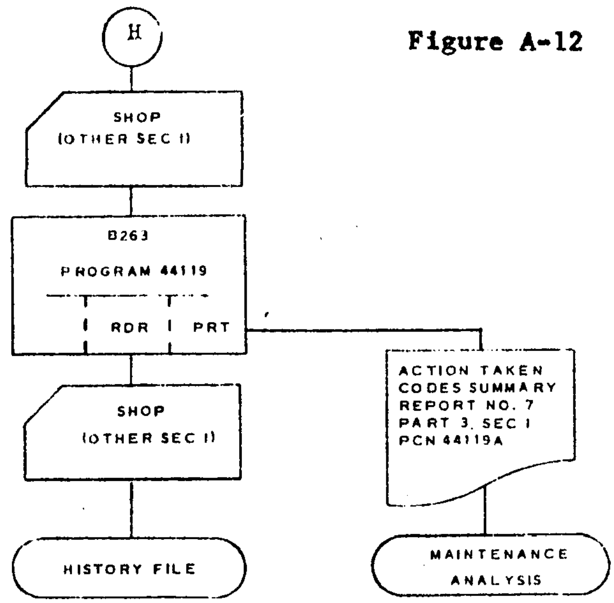


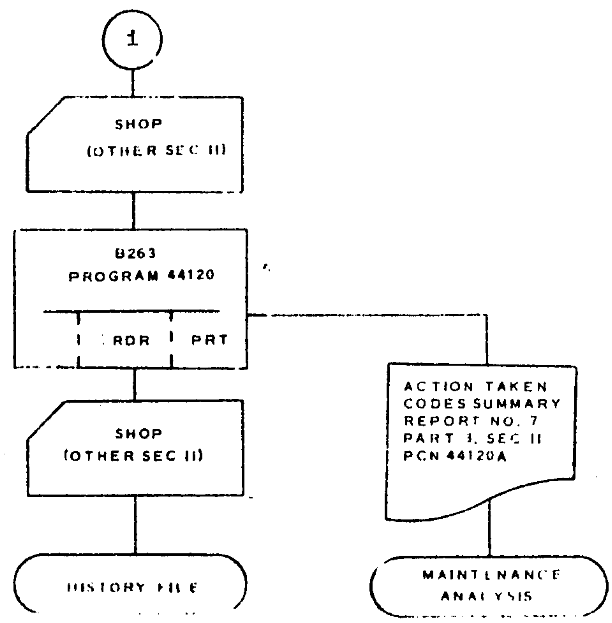
Source: AFM 171-IV, 41-A3-13

ACTION TAKEN CODES SUMMARY -- Continued

APPENDIX A -- Continued

Figure A-12



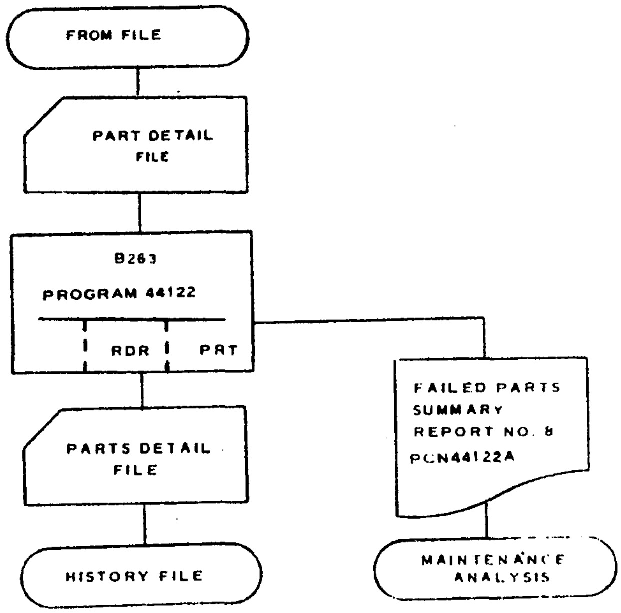


Source: AFM 171-IV, 41-A3-13

FAILED PARTS SUMMARY

APPENDIX A -- Continued

Figure A-13

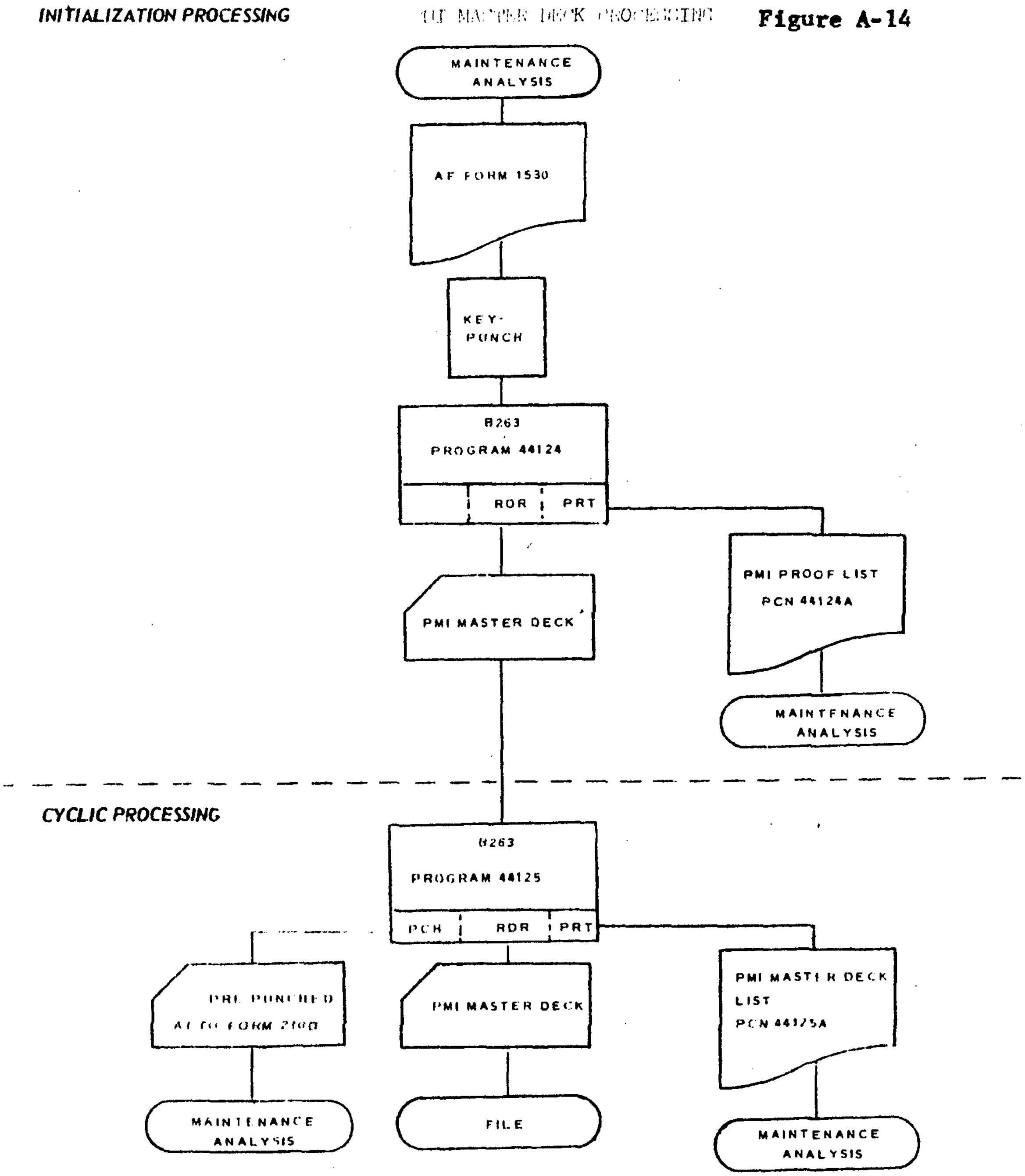


Source: AFM 171-IV, 41-A3-14

PREVENTIVE MAINTENANCE SCHEDULING

APPENDIX A -- Continued

Figure A-14



Source: AFM 171-IV, 41-A3-15

1. JOB CONTROL NO.	2. WORK CENTER	3. I. D. NO./SERIAL NO.	4. MDS	5. W. O. NO. PREFIX / SUFFIX	6. TIME	7. PRI	8. SORTIE NO.	9. LOCATION

10. ENG. TIME	11. ENGINE I.D.	12. INST. ENG. TIME	13. INST. ENG. I.D.	14.	15.	16.	17. TIME SPEC. REQ.	18. JOB STD.

19. FSC	20. PART NUMBER	21. SER. NO./OPER. TIME	22. TAG NO.	23. INST. ITEM PART NO.	24. SERIAL NUMBER	25. OPER. TIME

	A CARD AND ITEM NO.	B TYPE MAINT	C WORK UNIT CODE	D ACTION TAKEN	E WHEN DISC	F HOW MAL	G UNITS	H START DAY	H START HOUR	I STOP DAY	I STOP HOUR	J CREW SIZE	K MAN NUMBER
1													
2													
3													
4													
5													

26. DISCREPANCY

27. CORRECTIVE ACTION

28. RECORDS ACTION

AFTO FORM JAN 68 349 **MAINTENANCE DATA COLLECTION RECORD** M & W INC. 9-67 120MM

Figure A-15

<u>Human Judgement Blocks</u>: D. Action Taken - 33 different codes

E. When Disc - 21 different codes

F. How Mal - over 900 different codes

Figure A-15 -- Continued

29. PARTS REPLACED DURING REPAIR						
LINE NUMBER	A FSC	B PART NUMBER	C WORK UNIT CODE	D REF. SYMBOL	E HOW MAL	F QTY.

30. CONTINUATION FROM BLOCK ________

Back of AFTO 349 Form.

APPENDIX B

Production Control Number Reports

Source: U. S. Air Force Maintenance Management, AMF 66-1, Department of the Air Force, June 1966 (unclassified).

APPENDIX B -- (cont'd.)

Purposes of Product Control Number Reports

(1) DAILY PRODUCTION REPORT - REPORT NO. 1

Provide maintenance management with a daily record of the distribution of the manhours and units produced. This information will be used in planning and scheduling of daily requirements.

(2) MONTHLY PRODUCT SUMMARY - REPORT NO. 2

To provide maintenance managers with a monthly tabulation of labor hours expended by each work center. Management will use this report in the distribution and planning of future workload requirements.

(3) MONTHLY LABOR HOURS SUMMARY - REPORT NO 3, PARTS 1-5

To provide maintenance managers with a monthly tabulation of labor hours expended by each work center. Management will use the report for planning labor.

(4) MONTHLY WORK ORDER SUMMARY - REPORT NO. 4

To furnish a report of the units produced and hours expended by the work centers on each work order. Information will be used for budget and accounting purposes, as well as source data for planning and scheduling.

(5) SYSTEM AND COMPONENT SUMMARY - REPORT NO. 5

Provide five monthly reports, shop (failures and non-failures) and support general of all work performed on aircraft and items processed through maintenance shops. Maintenance managers will use this information to determine the components that malfunction most frequently and those jobs that consume appreciable quantities of maintenance labor.

(6) END ITEM MALFUNCTION SUMMARY - REPORT NO. 6

Furnishes a list of the labor hours and units produced required to keep each individual air vehicle or trailer in operation. This data is used primarily to increase the effectiveness of the inspection cycle and reduce work being done between inspections, etc.

APPENDIX B -- (cont'd.)

(7) ACTION TAKEN CODES SUMMARY - REPORT NO. 7

Furnish a report of the units produced by the shops in support of service and NRTS requirements. This information will be used to evaluate the base repair capabilities.

(8) FAILED PARTS SUMMARY - REPORT NO. 8

To provide managers with a recap of all bits and pieces that failed during the month. Information will be used for comparison and surveillance of parts or bits that fail on a recurring basis.

(9) PRECISION MEASUREMENT SCHEDULE - REPORT NO. 9

To provide various reports to assist in the scheduling of PME.

APPENDIX B -- (cont'd.)

List of Abbreviations Used in PCN Reports

A.	Action Taken Code.
AOD.	As of Date.
ASTED.	Assisted Work Center.
ASTNG.	Assisting Work Center.
BOR HR.	Borrowed Hours.
BWC HR.	Basic Work Center Hours
COMP.	Component
D.	When Discovered Code.
FSC.	Federal Supply Class.
ID.	Identification Number.
JOB HR.	Job Hours.
LND.Hr.	Loaned Hours.
MAL.	How Malfunctioned Code.
NRTS.	Not Reparable This Station.
PAR.	Part Number.
PCN.	Product Control Number. The PCN is a six (6) digit number of which the first five (5) digits denote the computer program which produces the report. The last digit denotes shred-out of the report. A PCN is shown on each report.
PR.	Prefix (Work Order).
PREP.	Prepared.
QTY.	Quantity.
REF SY.	Reference Symbol.
RTP NO.	Report Number of Data Form.

APPENDIX B -- (cont'd.)

SER.	Serial Number.
SERV.	Serviceable.
SUF.	Suffix (Work Order).
SYS.	System.
UP.	Units Produced.
WC.	Work Center Number.
WO.	Work Order Number.
WUC.	Work Unit Code.

Figure B-1

PREP   WORK CENTER 13110   DAILY PRODUCTION - REPORT NO. 1   PCN4811VA

WUC	A	D	MAL	UP	END ITEM	PAR/SER	TIME	WO	DATE	BWC HR	ASTNG	BUN HR	ASTED	LND HR	RPT NOID
21FC8	R	M	381	01	VC054G	45005574	19552	AP5578CC	19056				61000	1.0	060708 0
21FCC	W	M	750	01					19056					1.0	060559 0
21KDO	G	M	105	01					19056					1.0	060561 0
				03 **										3.0 **	
				03 ***										3.0 ***	
12244	F	F	127	01	C118A	53003268	17180	AB3268CG	21056				22110	3.0	807335 0
				01 **										3.0 **	
				01 ***										3.0 ***	
14140	1	M	020	01	1560	5+87421+93		AP1291C3	20056				61000	.5	50M114 3
				01		5+87421+88			20056					.5	50M115 3
				02 **										1.0 **	
				02 ***										1.0 ***	
AF32B	C	F	070	01	4130	86057		GB005FAF	20056	.5					A81571 3
AF32B	F	F	070	00					20056		13120	1.0			A81571 0
AF32J	G	F	105	01	AF300	412055DF84873			22056				13410	4.0	384918 0
				02 **						.5 **		1.0 **		4.0 **	
				02 ***						.5 ***		1.0 ***		4.0 ***	
09140				00	004701	00M T 053544		XH3544HH	19056				13212	3.5	272051 0
				00 **										3.5 **	
				00 ***										3.5 ***	
09140				00	R28004	052W NK510054		XH005449	23056				99216	2.0	272114 0
				00					20056					3.0	272070 0
				00 **										5.0 **	
				00 ***										5.0 ***	
				08 ****						.5 ****		1.0 ****		19.5 ****	

Source: AFM 66-1 p. 9-24.

Figure B-2

PREP WORK CENTER Q214A MONTHLY PRODUCTION SUMMARY - REPORT NO. 2 PCN441128

PRE	SUF	OP	JOB HR	BWC HR	ASTNG	BOR HR	ASTED	LND HR	
AA	FJ	35	96.3	96.3					
		12	26.7		Q323A	26.7			
AB	FJ	40	63.6	63.6					
		25	72.0		Q323C	72.0			
		112 ***	258.6 ***	159.9 ***		98.7 ***			
AC	TC	06	20.6	20.6					
		17	37.6		Q323A	37.6			
		23 ***	58.2 ***	20.6 ***		37.6 ***			
AB	43	01	2.0				Q323A	2.0	
		02	4.0				Q323B	4.0	
		01	2.0				Q323C	2.0	
		04 ***	8.0 ***					8.0 ***	
AB	45	01	2.0				Q323A	2.0	
		01	2.0				Q323C	2.0	
		01	2.5				Q411B	2.5	
		03 ***	6.5 ***					6.5 ***	
AB	47	02	4.0				Q323C	4.0	
		01	2.0				Q323Z	2.0	
AC	47	01	2.0				Q323Z	2.0	
AD	47	02	4.0				Q323Z	4.0	
AF	47	01	2.0				Q324A	2.0	
		02	4.0				Q324B	4.0	
		01	2.0				Q324Z	2.0	
		10 ***	20.0 ***					20.0 ***	
AT	45	01	10.3	10.3					TCTO
		01	3.3				Q214A	3.3	
		01	8.0				Q313A	8.0	
		03 ***	21.6 ***	10.3 ***				11.3 ***	
		155 ****	372.9 ****	190.8 ****		136.3 ****		45.8 ****	

Source: **AFM 66-1, p. 9-25.**

Figure B-3

MONTHLY LABOR HOURS SUMMARY - REPORT NO. 3, PART 1 PCN4A113A

WC	PRE	SUF	JOB HR	BWC HR	BOR HR	LNU HR
13120	A	BN	10.0	6.0	2.5	1.5
		BP	14.0	5.0	6.0	3.0
	B	BP	5.0	2.0		3.0
		CB	2.5	1.0		1.5
			31.5***	18.0***	8.5***	9.0***
13130	A	BN	12.0	8.0	2.0	2.0
		BP	14.0	8.6	4.4	1.0
		CB	1.3	.8	.5	
		CX	1.3	.8	.5	
		FJ	1.2	.5	.2	.5
	B	FJ	2.4	1.0	.4	1.0
	X	FJ	1.2	.5	.2	.5
		HC	1.2	.5	.2	.5
			34.6***	20.7***	8.4***	5.5***
13140	A	BN	701.0	560.0	141.0	
		BP	100.0	75.0		25.0
		CX	99.9	90.0	9.0	.9
	B	CX	2.7	.9	.9	.9
			903.6***	725.9***	150.9***	26.8***
13141	A	BN	31.4	13.4	11.7	6.3
		BP	16.7	2.3	1.9	12.5
	X	FJ	172.8	11.1	33.3	128.4
			220.9***	26.8***	46.9***	147.2***

Source: AFM 66-1, pg. 9-26.

Figure B-4

PREP MONTHLY WORK ORDER SUMMARY REPORT NO. 4, PART 1 SECTION 1 (ON EQUIP) PCN44114A

WD	OP	HOURS	WC
AA 0000 MA	29	19.7	52103
	29 ***	19.7***	
AC 0000 MA	17	9.1	52103
	17 ***	9.1***	
AD 0000 MA	05	7.9	52103
	05 ***	7.9***	
	51 ****	36.7****	
AA 0000 MC	62	36.1	52101
	34	34.6	52102
	44	28.6	52103
	10	3.0	52200
	150 ***	102.3***	
AB 8682 MC	01	1.5	52103
AB 8683 MC	02	3.0	52102
AB 8688 MC	01	2.0	52101
AB 8692 MC	01	1.0	52102
	05 ***	7.5***	
AC 0000 MC	07	11.6	52101
	05	9.8	52102
	07	11.1	52103
	13	44.5	52200
AC 4365 MC	01	.4	52102
	33 ***	77.4***	
AD 0000 MC	05	25.7	52101
	04	19.9	52102
	05	22.9	52103
	00	14.7	53300
AD 4326 MC	01	.6	52101
	15 ***	83.8***	
	203 ****	271.0****	

Source: AFM 66-1, p. 9-27.

Figure B-4 -- Continued

MONTHLY WORK ORDER SUMMARY REPORT NO. 4, PART 2 SECTION II (OFF EQUIP) PCN441140

PREP WC	WO	OP	HOURS
13120	AP 2555 CB	00	1.0
	AP 5668 CB	00	2.0
		00 ***	3.0***
	AP 9070 CC	01	3.0
	AP 9089 CC	01	2.0
	AP 9095 CC	01	10.0
		03 ***	15.0***
	AB 9033 MX	01	2.0
		01 ***	2.0***
	SH 3133 SB	02	2.0
		02 ***	2.0***
	XK 0007 CB	01	2.0
		01 ***	2.0***
	XA 0136 TC	03	3.0
	XA 4017 TC	01	2.0
	XA 4764 TC	03	3.0
	XA 5413 TC	03	3.0
	XU 0733 TC	03	.2
		13 ***	11.2***
		20 ****	35.2****
13150	SP 9325 SC	12	2.7
	SP 9327 SC	10	2.6
	SP 9328 SC	17	3.1
	ST 9000 SC	16	1.9
		55 ***	10.3***
		55 ****	10.3****
13151	AP 7732 TC	01	.3
	AT 1666 TC	00	1.8
		01 ***	2.1***
	SP 8261 SC	02	5.0
	SP 8281 SC	04	2.2
	SP 8301 SC	02	5.0
		08 ***	12.2***
		09 ****	14.3****

Source: AFM 66-1, pg. 9-28.

Figure B-5

PREP SYS & COMP DISCREPANCY SUMMARY - REPORT NO. 5, PART 1 SEC 1 (ON-EQUIP FAIL) PCN44115A

WUC	A	D	MAL	UP	JOB HR	END ITEM	WO	SER	DATE	RPT NO	ID
AEBFB	L	G	127	1	1.3	FPS050V	4D12121A	0002	18029	0480010	0
				1*	1.3*						
AEBJF	L	G	127	1	.1	FPS050V	4D12121A	0002	18029	0480010	0
				1*	.1*						
				2**	1.4**						
AECAA	R	D	290	1	1.5	FPS050V	4B11011A	0002	20029	0515009	0
				1*	1.5*						
AECOO	R	D	037	1	1.0	FPS050V	4B11011A	0002	21029	0525009	0
	G	D	160	1	2.0		4B11031A		16029	0475002	0
	R	D	169	1	1.0		4B11011A		10029	0415014	0
				3*	4.0*						
AEDBO	L	G	127	1	.3	FPS050V	4D11021A	0002	06029	0370028	0
				1	.3		4D11011A		06029	0370027	0
				1	.2		4D11031A		06029	0370029	0
				3*	.8*						
				7**	6.3**						
				9***	7.7***						

Source: AFM 66-1, p. 9-29.

Figure B-6

PREP END ITEM MALFUNCTION SUMMARY NO. 6, PART 1 PCN44116A ADD

END ITEM	C054G	SER	450005602	WUC	A	D	MAL	UP	HOURS	WO	DATE	RPT NO	ID
				51722	P	F	037	1	2.0	AB560	22056	99M06	1
								1**	2.0**				
				51722	P	F	381	1	2.0	AB560	22056	99M05	1
					1	F	037	1	2.0		22056	99M05	3
								2**	4.0**				
								3***	6.0***				
								3****	6.0****				

Source: AFM 66-1, p. 9-30.

Figure B-7

PREP WC 13330 ACTION TAKEN CODES SUMMARY (SERV) REPORT NO. 7, PART 1 PCN44117A

PRE	SUF	WUC	FSC	PART NUMBER		TOTAL	A	F	G	K	L	Z
AB	CG	42142	6125	F145		1	1					
					***	1	1					
AB	CT	2113B	1680	31934		2		2				
					***	2		2				
AB	TB	4112A	1680	WB009+4		1			1			
					***	1			1			
AB	TB	4411G	6220	G3800A1		2				2		
					***	2				2		
AB	TG	46221	2915	201700+2		2					1	1
					***	2					1	1
AP	CC	42221	6110	1042+17A		1	1					
					***	1	1					
AS	C3	63200	5821	ANARC89		2			1	1		
					***	2			1	1		
GB	AM	ZZ995	5821	AM3078ART42		1						1
					***	1						1
					****	12	2	2	2	3	1	2

Source: **AFM 66-1, p. 9-30.1.**

Figure B-7 -- Continued

PREP WC	ACTION TAKEN CODES SUMMARY (SERV + NRTS) REPORT NO. 7, PART 4 NRTS	SERVICEABLE	TOTAL	%	PCN44121A
32103	33	192	225	85	
32104	42	86	128	67	
32111	39	44	83	53	
32117	28	67	95	71	
32200	20	59	79	75	
32211	1	9	10	90	
32212		4	4	100	
32213	83	101	184	55	
32215	77	5	82	6	
33500	153	383	536	71	
33501	85	85	170	50	
34324	127	53	180	29	
35301	14	66	80	83	

Source: AFM 66-1, p. 9-30.2.

Figure B-8

PREP	FAILED PART SUMMARY				REPORT NO. 8		PCN44122A		
WC	WO	WUC	FSC	PART NUMBER	HAL	REF SY	QTY	WUC	RPI NO
1	EG1234MZ	H0310	1630	12345	020	KIT	1		53B853
1	EG5678MZ	H0310	1630	12345	020	KIT	1		53B853
1	EG5678MZ	H0310	1630	12345	020	KIT	1		53B853
1	EG2345MZ	H0310	1630	12345	020	E1870	1	KIT	53B853
1	EG6789MZ	H0310	1630	12345	020	F1870	1	KIT	53B853
1	EG6789MZ	H0310	1630	12345	020	F1870	1	KIT	53B853
							6**		
1	EG3456MZ	H0310	1680	2468123	615	V3502	2	SEAL	97M557
1	EG7890MZ	H0310	1680	2468123	615	V3502	2	SEAL	97M557
1	EG7890MZ	H0310	1680	2468123	615	V3502	2	SEAL	97M557
							6**		
							12***		
1	EG4567MZ	H0320	1630	12345	120	V1702	5	KIT	97M557
1	EG8901MZ	H0320	1630	12345	120	V1702	5	KIT	97M557
1	EG8901MZ	H0320	1630	12345	120	V1702	5	KIT	97M557
							15**		
							15***		
							27****		

Source: AFM 66-1, p. 9-30.3.

Figure B-9

PRECISION MEASUREMENT (PME) SCHEDULE, RCS: 9-AF-K11
(REPORT NO. 10) (SECTION I)

WORK CENTER	DATE PREV CALIB/INSP	WORK UNIT CODE	CLASS CODE	PART NUMBER	SERIAL NUMBER	CALIB/INSP CYCLE	DATE DUE CALIB/INSP	LOCATION OF ITEM	TELEPHONE NUMBERS	UNITS	HOURS
W/C	PRE	W/U/C	CC	PART NUMBER	SER NO	I/C	D/D/C	BLDG	PHONE		HRS
Q4324	01015	YA180	6520	606F1	035251	030	01025	S-31	7265		.5
Q4324	01015	YA180	6520	750A	0B7528	030	01025	1085	422		2.1
Q4324	01015	YA180	6520	4SD4800-F1	280101A	030	01025	S-31	7265		2.1
Q4324	01015	YA180	6520	2SD150F2	U0306/E	030	01025	S-31	7265		1.0
										4	5.7*
Q4325	04084	WP000	6530	AN/ARM-11B	000322A	180	04025	568	632		.5
										1	.5*
Q4325	07114	XA000	6540	K1514TIRE	001058	090	07025	S-31	7265		2.1
										1	2.1*
Q4326	08015	YA180	6545	65D4800-F1	028030	030	08025	S-31	7265		2.1
										1	2.1*
Q4326	17015	YA180	6550	750AT-WRENCH	0B7523	030	17025	S-31	7265		2.5
										1	2.5*
Q4326	22114	WP700	6325	C-1	001557	090	22025	S-31	545		2.5
										1	2.5*
Q4324	23084	WJ000	6330	AN/USM-37	000146	180	23025	568	7302		.5
Q4324	23084	WJ000	6330	PRD-627A	001525	180	23025	568	7302		.5
Q4324	23114	WJ000	6330	TS-510/USM-44	000235	180	23025	568	7302		.5
										3	1.5*
										12	16.9**

Source: AFM 66-1, p. 9-31.

Figure B-9 -- Continued

PRECISION MEASUREMENT EQUIPMENT (PME) SCHEDULE, RCS: 9-AF-K11 (REPORT NO. 10) (SECTION II)

WORK CENTER	DATE PREV CALIB/INSP	WORK UNIT CODE	CLASS CODE	PART NUMBER	SERIAL NUMBER	CALIB/INSP CYCLE	DATE DUE CALIB/INSP	LOCATION OF ITEM	TELEPHONE NUMBERS	UNITS	HOURS
W.C	PRE I	W/U/C	CC	PART NUMBER	SER NO	I/C	D/D/C	BLDG	PHONE		HRS
Q4323	01084	WJ000	6530	PDR-627A	001525	180	01025	568	7302		.5
	01084	WJ000	6530	AN/USM-37	001465	180	01025	568	7302		.5
	01084	WJ000	6535	HP-475B	000861	180	01025	568	7302		.5
	03114	WJ000	6545	AN/PSM-6	014042	090	03025	568	7302		.5
	03084	WJ000	6535	MODEL 3401	010706	180	03025	568	7302		1.5
	03084	WJ000	6535	HP-715A	000173	180	03025	568	7302		2.5
										6	6.0*
	06015	WA000	6320	X-1A236/P	000113	030	06025	S-33	5227		1.5
	06014	WA000	6320	X-1A	000112	365	06015	S-33	5227		1.0
	06015	WA000	6320	2SD150F2	001099	030	06025	S-33	5227		1.5
	10114	WA000	6320	MOD 1552	078449	090	10025	S-33	5227		.7
	10114	WA000	6340	MOD 4552	064090	090	10025	S-33	5227		.9
	10114	WA000	6320	TV-7B/U2	001736	090	10025	S-33	5227		.5
	10114	WA000	6340	TS-328A/U	001706	090	10025	S-33	5227		1.0
	10114	WA000	6340	MOD 622	020120	090	10025	S-33	5227		1.0
										8	8.1*
										14	14.1**

Source: AFM 66-1, p. 9-32.

APPENDIX C

Performance Evaluation

APPENDIX C -- (cont'd.)

Performance Evaluation

"System Availability" as a Measurement of System Performance for MIP

System Availability has been chosen as the mathematical model for expressing the performance of the "Missile Impact Prediction Set" (MIP) equipment.[1]

By definition, System Availability in a static condition is a function of reliability, maintainability and supply effectiveness.[2] Mathematically it may be expressed in this general way:

$$A_2 = f(R_s, M_s, S_s) \qquad (1)$$

where A_s = availability

R_s = reliability

M_s = maintainability

S_s = supply effectiveness

It may also be expressed in a more precise form as:

$$A_s = \frac{MTBF}{MTBF_s \quad MTR_s \quad MTW_s} \qquad (2)$$

where A_s = availability of the system

$MTBF_s$ = mean-time between failures of the system, reflecting reliability

MTR_s = mean-time-to-repair, reflecting maintainability

MTW_s = mean-time-waiting for a spare, reflecting supply

---

1 See Glossary for precise description of equipment group.

2 A. S. Goldman, Op. cit., p. 26.

The MTW_s function at this time can be considered negligible, therefore:

$$A_s = \frac{MTBF_s}{MTBF_s \quad MTR_s} \tag{3}$$

The data reported in the project are the combined observations by contractor Equipment Controller monitoring personnel and Automatic Systems Checkout Monitoring Equipment, and hence they are regarded as highly accurate. A five year history of MIP I and MIP II is as follows:

Table C. 1

MIP MTBF - MTR

MIP I			MIP II		
Year	MTBF	MTR	Year	MTBF	MTR
1964	142.24	0.73	1964	135.52	1.12
1965	243.67	0.70	1965	203.31	0.69
1966	640.97	1.09	1966	289.24	0.78
1967	289.87	1.31	1967	362.71	1.26
1968	173.42	1.30	1968	335.13	0.86

Source: Maintenance/Equipment Status Logs for 1964-1968.

Table C. 2

MIP I SYSTEM AVAILABILITY 1964-1968

1964	$A_1 = \dfrac{MTBF_1}{MTBF_1 + MTR_1}$	$= \dfrac{142.24}{142.24 + 0.73}$	=	99.48
1965	$A_1 = \dfrac{MTBF_1}{MTBF_1 + MTR_1}$	$= \dfrac{243.67}{243.67 + 0.71}$	=	99.71
1966	$A_1 = \dfrac{MTBF_1}{MTBF_1 + MTR}$	$= \dfrac{640.97}{640.97 + 1.09}$	=	99.83
1967	$A_1 = \dfrac{MTBF_1}{MTBF_1 + MTR}$	$= \dfrac{289.87}{289.87 + 1.31}$	=	99.55
1968	$A_1 = \dfrac{MTBF_1}{MTBF_1 + MTR}$	$= \dfrac{173.42}{173.42 + 1.30}$	=	99.25

Source: Calculated from Table C. 1.

Table C. 3

MIP II SYSTEM AVAILAVILITY 1964-1968

1964	$A_2 = \frac{MTBF_2}{MTBF_2 + MTR_2}$	$= \frac{135.52}{135.52 + 1.12}$	=	99.18
1965	$A_2 = \frac{MTBF_2}{MTBF_2 + MTR_2}$	$= \frac{203.31}{203.31 + 0.69}$	=	99.66
1966	$A_2 = \frac{MTBF_2}{MTBF_2 + MTR_2}$	$= \frac{289.24}{289.24 + 0.78}$	=	99.73
1967	$A_2 = \frac{MTBF_2}{MTBF_2 + MTR_2}$	$= \frac{362.71}{362.71 + 1.26}$	=	99.65
1968	$A_2 = \frac{MTBF_2}{MTBF_2 + MTR}$	$= \frac{335.13}{335.13 + 0.86}$	=	99.74

Source: Calculated from Table C. 1.

Table C.4

MIP CM-PM LABOR HOURS-1967

	MIP I			MIP II		
MONTH	CM	PM	TOTAL	CM	PM	TOTAL
DEC.	31.1	99.7	130.8	50.3	98.1	148.4
NOV.	23.5	101.8	125.3	27.5	93.6	121.1
OCT.	23.0	98.9	121.9	27.2	88.2	115.4
SEPT.	7.7	102.7	110.4	59.0	111.6	170.6
AUG.	76.0	95.7	171.7	106.2	97.2	203.4
JULY	14.8	114.4	129.2	41.7	93.8	135.5
JUNE	74.8	118.4	193.2	25.4	124.3	149.7
MAY	56.5	112.6	169.1	73.6	115.6	189.2
APRIL	72.8	116.9	189.7	15.7	113.0	128.7
MARCH	8.1	98.4	106.5	22.5	116.8	132.3
FEB.	68.1	101.7	169.8	55.0	95.1	150.1
JAN.	15.9	85.5	101.4	28.1	97.5	125.6
	472.3	1246.7	1719.0	532.2	1244.8	1770.0

Source: PCN 44114A Rept. 4, Part I, Group I.

Table C. 5

MIP CM-PM LABOR HOURS-1968

	MIP I			MIP II		
MONTH	CM	PM	TOTAL	CM	PM	TOTAL
DEC.	41.2	105.1	146.3	48.2	105.0	153.2
NOV.	59.3	66.2	125.5	55.4	95.9	151.3
OCT.	3.8	88.0	91.8	27.7	81.5	109.2
SEPT.	64.7	99.5	164.2	14.3	86.6	100.9
AUG.	28.4	94.2	122.6	26.8	94.8	121.6
JULY	26.0	119.9	145.9	34.9	79.3	114.2
JUNE	22.6	80.6	103.2	22.3	114.7	137.0
MAY	85.5	100.4	185.9	24.7	99.9	124.6
APRIL	61.6	139.1	200.7	20.7	101.1	121.8
MARCH	3.7	92.5	96.2	26.6	97.4	124.0
FEB.	23.3	81.5	104.8	1.9	88.8	90.7
JAN.	12.3	97.8	110.1	23.1	92.4	115.5
	432.4	1164.8	1597.2	326.6	1137.4	1464.0

Source: PCN 44114A Rept. 4, Part I, Group I.

Analysis of the preceding tables indicates that after the break-in period, MIP II has improved from 99.18 in 1964 to 99.74 in 1968. MIP I,improved from 99.48 in 1964 to 99.83 in 1966, has moved downward since that time.

A check of the corrective maintenance and preventive maintenance manhours (only available data 1967-1968 and reported in Table C. 4 and C. 5) has disclosed no unusual expenditure of effort; The performance of this "equipment chain" compares favorably with maintenance standards projected from design expectations and past performance of comparable systems.[3]

[3]Manus R. Munger & M. Paul Willis, Development of an Index of Electronic Maintainability, (Pittsburgh: American Institute for Research) 1959.

APPENDIX C -- (cont'd.)

A Measure of Overall System Performance

The following unclassified article presented in the BMEWS B.R.A. publications of the Hotline (24 March 1969) presents an accurate picture of the overall BMEWS System performance:

> Operational requirements provide for the uninterrupted Detection Radar coverage in all three of the sectors. A total time of two minutes is allowed for switching equipment for maintenance or changing operational configuration. If this period is exceeded, the Site is considered to be Red, and Green Time must again start from a base of zero time.
>
> Site II exceeded 1,000 hours of Green Time for the first time in July of 1962 when the total period crossed 1,153 hours. The 2,000 hour mark was surpassed in May of 1965 with 2,056 hours. In February of 1966, three thousand hours were achieved and exceeded for the first time.
>
> The all-time BMEWS System Green Time record was experienced at Clear in January of 1968 with a grand total of 3,458 hours 53 minutes. All together, Clear has exceeded the 1,000 hour period a total of 15 times to date since October of 1961 (the start of formal total coverage).

At the present time BMEWS at Alaska is operating on an extended run of over 3,200 hours of continuous operation. In summary, while the equipment maintenance might be improved further or accomplish more efficient cost-wise, its record of operational performance is generally considered exceptionally favorable.

Absence - Tardiness Seasonal TIME SERIES INDEX

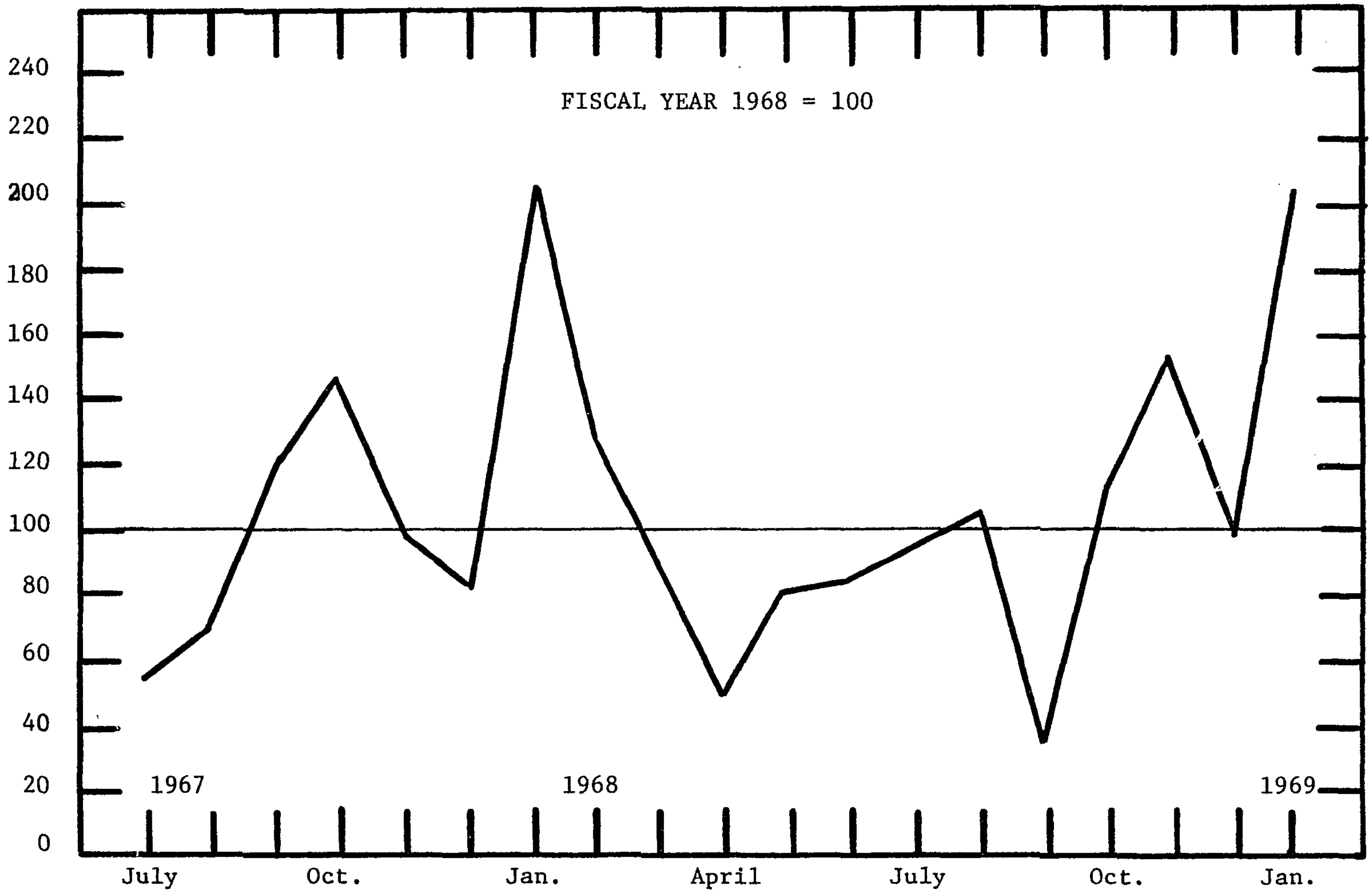
Absence and tardiness hours used in the Seasonal Trend Index Chart (Figure C. 1) are based on the Data Systems Work Center's records. This work area represents a majority of the total technicians who reported the maintenance actions analyzed in Chapters IV and V.

Available absence and tardiness records started in July of 1967 so consequently fiscal year 1968 was chosen to average 100.0. As might be expected, considering the extreme cold experienced during January, February and March, the winter months showed the greatest absence and tardiness. This is the period of almost total darkness; cars and aircraft do not function properly; trailers and homes "freeze up." Added to the inherent climatic problems of the subarctic winter were six different power failures during the total time period covered -- the electric power for civilian use is furnished by a commercial electric utility.

The degree to which this bleak environment affects maintenance personnel morale is an excellent research study for a qualified sociologist; however, there is some basic evidence available to even the layman that "cabin fever" presents a question of maintenance data reporting accuracy during extreme temperature drops (-40 degrees or lower). In the author's opinion, based on numerous interviews, there are some personnel who are not concerned with what they consider trivia (accurate data reporting?) during these difficult periods, and will accomplish only the necessary tasks.

FIGURE C. 1

ABSENCE-TARDINESS SEASONAL TIME SERIES INDEX



Source: Data Systems Weekly Absence Records

Inconsistencies in Data Reporting

Generally, the lower control limit of a subsystem's CM fix actions is ignored. A spot check of MIP in May, 1968 revealed some reporting inconsistencies. Included below is a "Problem Referral Brief" from Systems Maintenance Analysis to the reporting center.

DATE: 18 May 1968

TO: Data Systems Work Center

FROM: System Maintenance Analysis

SUBJECT: Inconsistencies in Data Reporting

Problem:

Analysis of the April PCN reports reveals some inconsistencies in the reporting of End Item FSQ028 (MIP).

Backup Data:

PCN Report No. 5, Part I, Section I for April listed a total of seventeen fix actions for MIP I and MIP II. This figure is far below the mean average of forty-four per month and further study was initiated.

Listed below are all the corrective maintenance actions for MIP I and MIP II reported in the Site Maintenance/ Equipment Status log for the month of April:

MIP NO.	TIME	STATUS	CAUSE	REMARKS	DATE
2	0800-0855	Y	CM	Investigate Core Oil Leaks	2*
2	1639-1640	R	CM	Loss Power on COS	3*
2	1643-1644	R	CM	Loss Power on COS	3*
1	1726-1753	Y	CM	Heat Exchanger Replaced Core B	3
2	1753-1757	R	CM	COS Power Dropped Out	3*
1	1753-1852	R	CM	Core B Heat Exchanger Replaced	3
1	2206-2210	R	CM	Core B Heat Ex. Troubleshoot	3
1	2225-2259	R	CM	Core B Heat Ex. Replaced	3
2	0006-0106	Y	CM	COS Power Troubleshooting	4*
1	0913-0914	R	CM	Recycle Program	9*
2	2251-2340	R	CM	Connect Core Cooling Plugs	9

Inconsistencies in Data Reporting (cont'd.)

MIP NO.	TIME	STATUS	CAUSE	REMARKS	DATE
1	0819-1023	R	CM	Motor Generator Replaced	13*
1	2219-0432	R	CM	Motor Generator Replaced	17-18
1	0545-0747	R	CM	Blower Motor on MG Bad	18*
2	0547-0548	R	CM	TDP Red Power Down on D.C.	18*
1	1315-1515	Y	CM	Investigate loss of Transm.	18
1	0730-0731	R	CM	Program Hangup	21*
1	1045-1046	R	CM	Program Hangup	22
1	1222-1223	R	CM	Program Hangup	22
1	1224-1225	R	CM	Program Hangup	22
1	1336-1337	R	CM	Program Hangup	23
1	1340-1341	R	CM	Program Hangup	23
2	1343-1640	Y	CM	Diagnostics	23
1	1957-2033	R	CM	MIPSOP Won't Load	23*
1	2243-2244	R	CM	Program Hangup	25*
1	2244-2400	Y	CM	Troubleshooting	25*
1	0047-0048	R	CM	Program Hangup	27*
1	0048-0049	R	CM	Program Hangup	27*
1	0814-0815	R	CM	Program Hangup	27*
1	0815-0816	R	CM	Program Hangup	27*
1	1604-1605	R	CM	Program Hangup	29*
1	1605-1858	Y	CM	Troubleshooting	29
1	1101-1102	R	CM	Program Hangup	30*
1	1124-1125	R	CM	Program Hangup	30*
1	1125-1126	R	CM	Program Hangup	30*
1	1126-1425	Y	CM	Replace Core B.S.A.	30
1	2006-2007	R	CM	Program Hangup	30*
1	2011-2400	Y	CM	Troubleshooting	30

*The dates represented by an asterisk were not reported by the Work Area with an AFTO 349. Job Control Numbers were not assigned also.

Conclusion:

Reporting errors are evidenced in FSQ028 Work Area by inconsistencies in the PCN data, the AFTO 349 data and the Maintenance/Equipment Status Log for the month of April.

Recommended Action by Receiving Agency:

Closer supervision of the reporting techniques and increased training on the new MMICS program.

GLOSSARY

Automatic Test Equipment - Equipment which carries out a predeterminal program of testing for possible malfunction without reliance on human intervention; also called automatic checkout equipment.

Automatic Testing - The process by which the localization of faults, possible prediction of failure, or validation that the equipment is operating satisfactorily is determined by a device that is programmed to perform a series of self-sequencing test measurements without the necessity of human direction after its operations have been initiated.

Availability - The percent of time in a specified period that a reporting configuration performed at an acceptable operability level.

Availability, Real Time - The percent of total time in a period that a reporting configuration performed at an acceptable operability level.

Ballistic Missile - A surface-to-surface missile which follows a ballistic (free-flight) trajectory from burnout to impact.

Bench Check - Any action by maintenance indetermining the condition status of an item and/or the determination of capability or lack of capability to return an item, removed for a malfunction or an alleged malfunction, to a serviceable status. It also includes repair action when accomplished concurrently with the Bench Check.

BMEWS Full Configuration - The provision of three forward radar sites connected to the BMEWS CC&DF in the Continental United States. This configuration provides for both detection and tracking radars at each of the forward radar sites (Thule, Greenland; Alaska; and Fylingdales, United Kingdom).

Chain, Equipment - A group of equipments that are functionally in series. The failure of one or more of the equipments results in loss of the function.

Chain, Radar Equipment - A group of equipments (associated with a particular radar beam) which are functionally in series. This group of equipments may for example include a full-power transmitter, a receiver (V and H channels), and IF group (V and H), a DFB, and a DTO.

Code - Any system of communications in which arbitrary groups of symbols represent units of plain text of varying length. Codes may be used for brevity or for security.

Correlation - The degree of statistical dependence between two sets of data, numerically expressed as the correlation coefficient.

Condemned - That state in which an article either cannot be repaired or the estimated cost of repair including material and labor exceeds the maximum repair allowance established for the effected article (ususally 65%).

Criteria - The specified performance requirement, either a design specification or an operational standard.

Deferred - The delay in returning an item to a serviceable status due to awaiting parts; lack or required documents, specifications, drawings, etc.; higher priority maintenance.

Detection Radar - An AN/FPS-50(V) radar used to survey a certain volume of space to detect any object passing through that volume and to transfer the resulting detected data to other sections of the BMEWS for processing and evaluation.

Diagnostic Analysis - The art of pinpointing troublespots and of quantitatively describing the nature of the difficulty by making use of professional knowledge, experience, and insight, together with the tools of scientific analysis.

Fix Action - The process of returning an item to a specified condition including preparation, fault location, item procurement, fault correction, adjustment and calibration, and final test.

Functional Check - Any action by maintenance personnel to determine the condition status of an item withdrawn from supply stocks prior to use or placement into shops for compliance with series age control technical orders.

Human Factors - Human psychological characteristics related to complex systems, and the development and application of principles and procedures for accomplishing optimum man-machine integration and utilisation. The term is used in a broad sense to cover all biomedical and psychosocial considerations pertaining to man in the system.

Maintainability - A characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources.

Maintainability Index - A quantitive figure of merit which relates the maintainability of an item to a standard reference.

Maintenance - All actions necessary for retaining an item in, or restoring it to, a serviceable condition. Maintenance includes servicing, repairs, overhaul, inspection, and condition determination.

Maintenance, Corrective - Scheduled maintenance performed to correct a degradation prior to the occurence of an unacceptable operability condition and unscheduled maintenance performed to investigate and correct an unacceptable operability condition.

Maintenance, Preventive - A procedure of inspecting, testing, and reconditioning all equipment at regular intervals according to specified instructions, intended to prevent failures in service to retard deterioration.

Mean Downtime - The average duration of periods, the system, subsystem, sectors, and equipments are inoperable.

Mean Time Between Failures - The ratio of acceptable operating time in a specified period to the total number of unscheduled corrective maintenance events in that same period.

Mean Time To Restore - The ratio of unscheduled corrective maintenance time in a period to the total number of unscheduled corrective maintenance events in the period.

Missile Impact Predictor - Each of the BMEWS radar sites has a Missile Impact Predictor (MIP) set. This set consists of two IBM 7090 computers, and such auxiliary equipment as is required to process, in real time, data from the radar subsystems, and to output its results to the Transmitting Data Programmer (TDP) for transmission to the Central Computer and Display Facility (CC&DF).

NRTS - Not Repairable This Station.

Performance Evaluation - The determination and interpretation of operational performance in comparison with criteria.

Reliability - The probability that a configuration will perform its intended function acceptably for a specified period of time when used in the manner and for the purpose intended.

Standard Data System - An automated Air Force data system that is common to two more commands and uses uniform:

(a) external preparatory procedures;
(b) inputs;
(c) file content;
(d) processing or computational logic;
(e) outputs produced without deviation of content, format or responsiveness.

<u>System Checkout</u> - At each site, the subsystem to: simulate raid inputs to the site and verify that the site responds properly to the raids; to perform dynamic automatic monitoring; to insert static targets; and to perform other system checks.

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